Fermilab

Particle Physics Division

Mechanical Department Engineering Note

Number: MD-Eng-210 Date: Jan 25, 2010

Project: DECAM

Project Internal Reference: MCCDTV LN2 Cooling System

Title: DECAM MCCDTV Cryogenic Safety Review Documents

Author(s): Herman Cease

Reviewer(s): Cryogenic Safety Subcommittee

Key Words:

Abstract/Summary:

Applicable Codes:
ASME DIVISION I SECTION VIII,
ASME B16.5 Pipe Flanges and Flanged Fittings

Cryo-Review for the
DECam Multi-CCD Test Vessel
Closed Loop LN2 System Test in Lab A

System Description:

A new installation is being planned for the Dark Energy Camera project. The new installation will be used to cool the Multi-CCD test vessel (MCCDTV) using a closed loop LN2 system. The MCCDTV is currently in the Lab A control room at Sidet and is being cooled using the LN2 autofill system previously reviewed. The MCCDTV will be moved to under the dome at Lab A and will be cooled using the new LN2 closed loop cooling system. The closed loop plumbing will be attached to the vessel via a triple jacketed hose, supply, return and the vacuum jacket. The LN2 reservoir, pump, and circulation station will be outdoors just outside Lab A very near the existing 500 L dewar used on the autofill system. The new closed loop cooling system operates at 100 psig.

Once the system is operational, several phases of testing will proceed. The phases are listed.

Phase I	**August 2008** Located at Floor Elevation Run Closed loop LN2 system in Lab A Simple Heat Exchanger
Phase II	**August 2008** Located at 40 Foot Elevation Run Closed loop LN2 system in Lab A Simple Heat Exchanger
Phase III	**September 2008** Located at Floor Elevation Run Closed loop LN2 system in Lab A Heat exchanger installed in Multi-CCD Test Vessel
Phase IV	**Fall 2008** Located at Floor Elevation Run Closed loop LN2 system in Lab A Heat exchanger installed in Multi-CCD Test Vessel MCCDTV installed in a rotation box
Phase V	**2008-2009** Operate Multi-CCD Test Vessel in lab A using closed loop LN2 system
Phase VI	**2009-2010** MCCDTV installed on Telescope simulator Full length of piping simulating, Vessel rotates

Operations with the new closed loop LN2 system and the MCCDTV under the dome at Lab A are expected to last until 2010.

H. Cease 8/14/08

Document List
Documents are prepared and stored in http://des-docdb.fnal.gov document #1537

1a. 200L Vessel Engineering Note
- Pressure_Vessel_Enote_200L-LN2-LABA-5031_8-14-08.doc
- PHPK_CODE_STAMP.JPG
- PHPK-VacuumV_note_07-1793-9911A.pdf PHPK Vacuum Vessel note
- PHPK_PressureV_Note_07-1793-9910.pdf PHPK Pressure Vessel note
- PHPK_Pressure Tests.pdf
- PHPK_DWG_07-1963-0500A.pdf
- PHPK_U1A Date Report.pdf

1b. 200L, 18 inch flange Engineering note
- ENOTE-18INCH_FLANGE_8-1-08.doc
- 18inch-flange-asme-calcs_8-1-08.xls
- 436426_assy.pdf
- 436428-RevB_flange.pdf
- 436466_RevB_weldment.pdf
- 436552_pad9.pdf
- 436553_pad5_6.pdf
- 436554_pad8.pdf
- FNAL_WelderCert.pdf

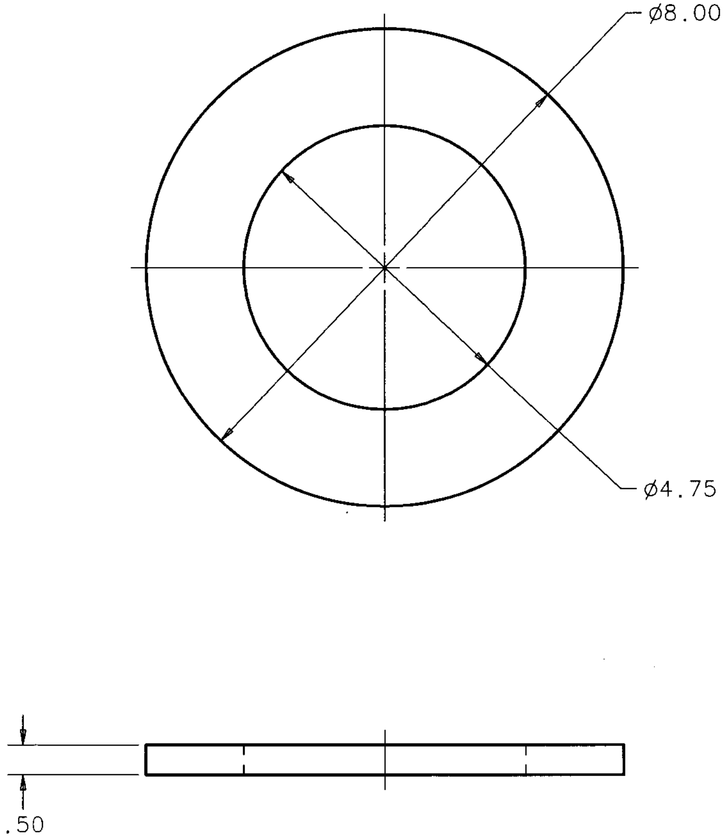
1c. 200L, 18 inch flange pressure test
- PRESSURE_TEST_PROCEDURE_200L_Flange.doc
- PRESSURE_TEST_PERMIT_200L_Flange_5034.doc
- PRESSURE_TEST_JHA_200L_Flange.doc

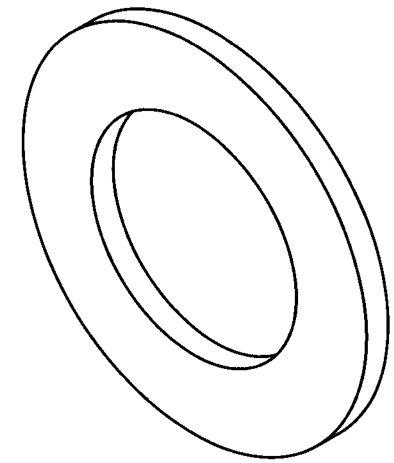
2. Process and Instrumentation Diagram 7-31-08
   - Process and Instrument Diagram - ME-436389REVA
3. Instrumentation and Valve List 8-11-08
   - LAB_A_LN2TEST_Valve-Instrument-List-8-11-08.xls
4. Failure Mode and Effect Analysis
   - DES_LAB_A_FMEA_8_11_08.xls
5. What if Analysis
   - DES_LAB_A_WHAT_IF.doc
6. Operating Procedures
   - DECAM_Lab_A_LN2_System_Op_Proceed_Rev_0_8-7-08.doc
7. MCCDTV SiDet ODH analysis with the LN2 installation inside Lab A
   - SiDet ODH Analysis-3-10-08.doc
   - SiDet ODH Analysis-3-10-08.xls
   - LN2_SOURCES_SIDET_FACILITY.pdf
8. FESHM 5031.1 Engineering Note for Piping Systems.
   - FESHM 5031.1 PIPING ENGINEERING NOTE FORM
   - DECAM_Lab_A_LN2_piping_Eng_Note_8-11-08.doc
   - ASME B31.3 Radiography report
   - 200L-LN2-LABA-trapped volume.doc
   - Fermi_Triple_Jacketed_dwgs.pdf

Recommendation letter to start operations from Cryo-Review Panel 8-14-08
- DECam LN2 Closed Loop Recommendation.doc

H. Cease 8/14/08

REV	DESCRIPTION	DRAWN / APPROVED	DATE / DATE





ISOMETRIC VIEW

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	H.CEASE	02-APR-2008
.XX	.XXX	ANGLES	DRAWN	B.ELLISON	02-APR-2008
± .02	± •••	± •••	CHECKED	J.RAUCH	04-APR-2008
1. BREAK ALL SHARP EDGES .015 MAX. 2. DO NOT SCALE DRAWING. 3. DIMENSIONS BASED UPON ASME Y14.5M-1994 4. MAX. ALL MACH. SURFACES 125√ 5. DRAWING UNITS: U.S. INCH			APPROVED	H.CEASE	04-APR-2008
			USED ON	ME-436466	
			MATERIAL	304-SST	

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

DECAM/CCDS
TEST VESSEL ASSEMBLY
4.75 I.D. REINFORCEMENT PAD

SCALE	DRAWING NUMBER	SHEET	REV
1:2	4900.120-MB-436552	1 OF 1	

CREATED WITH : Ideas12NXSeries GROUP: PPD/MECHANICAL DEPARTMENT

Created: 10:59:03 on 07-04-08 (D-M-Y) By: ellison State: 3-RELEASED

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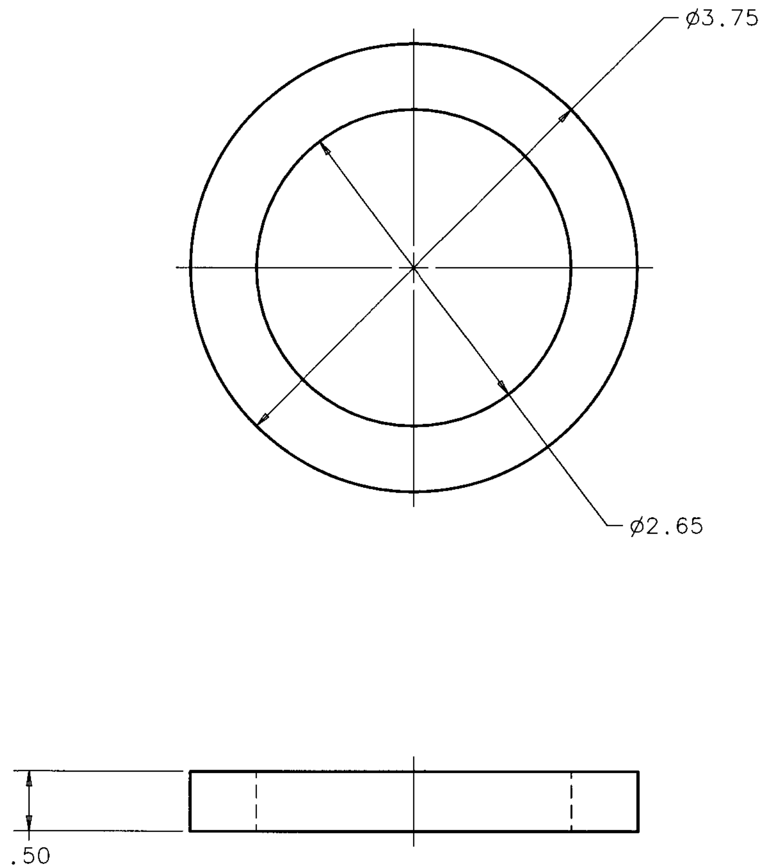
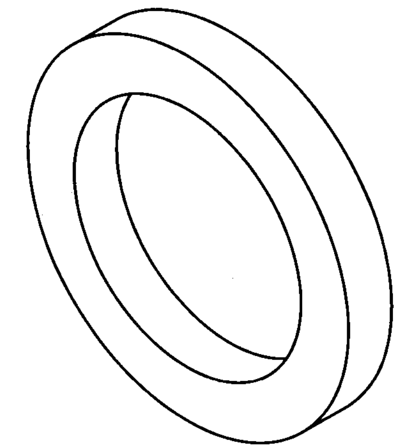
		APPROVED	DATE





ISOMETRIC VIEW

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	H.CEASE	02-APR-2008
.XX	.XXX	ANGLES	DRAWN	B.ELLISON	02-APR-2008
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			APPROVED	H.CEASE	04-APR-2008

1. BREAK ALL SHARP EDGES .015 MAX.
2. DO NOT SCALE DRAWING.
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4. MAX. ALL MACH. SURFACES 125
5. DRAWING UNITS: U.S. INCH

USED ON: ME-436466

MATERIAL: 304-SST

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DECAM/CCDS
TEST VESSEL ASSEMBLY
2.65 I.D. REINFORCEMENT PAD

SCALE	DRAWING NUMBER	SHEET	REV
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CREATED WITH : Ideas12NXSeries | GROUP: PPD/MECHANICAL DEPARTMENT

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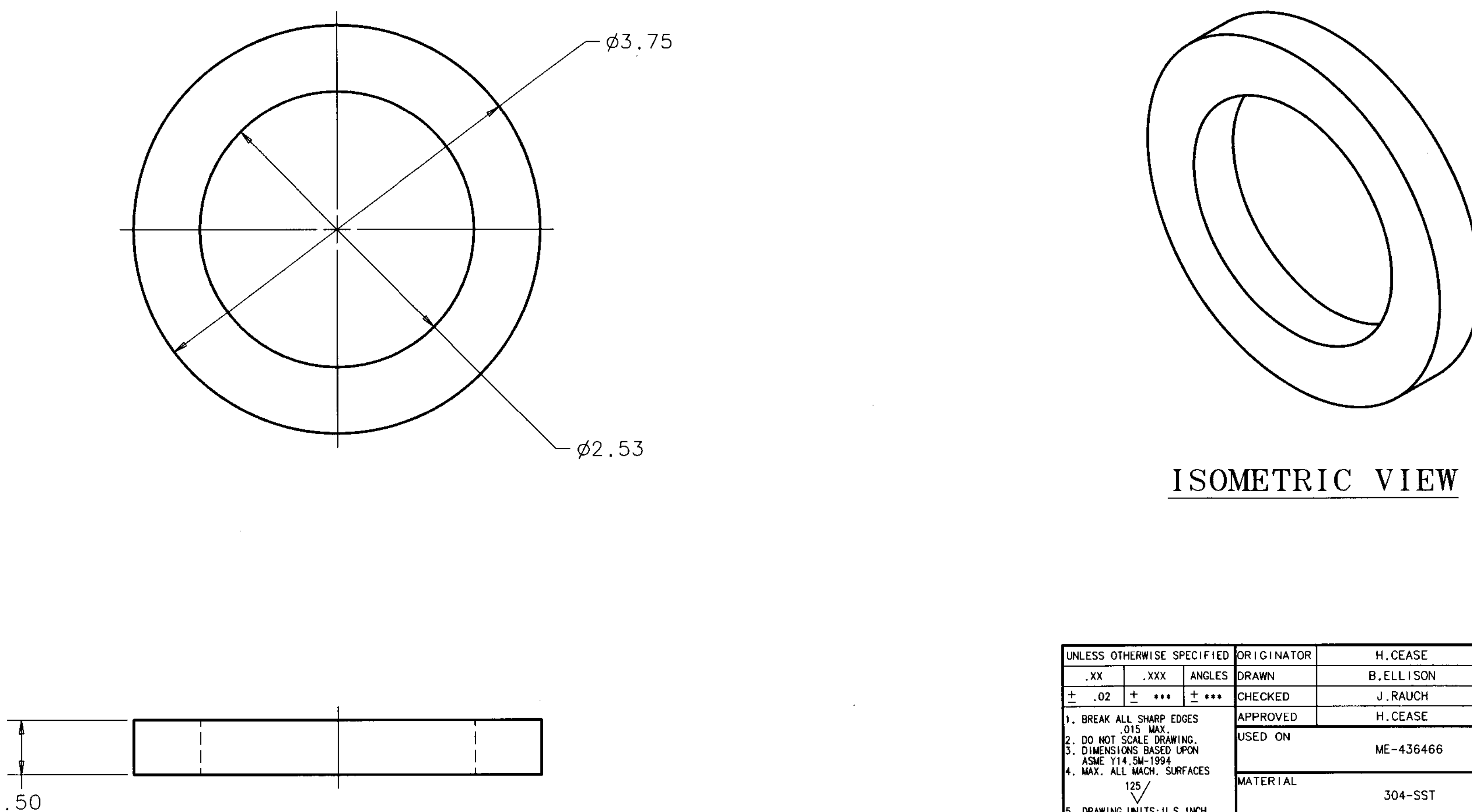

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	H.CEASE	02-APR-2008
.XX	.XXX	ANGLES	DRAWN	B.ELLISON	02-APR-2008
± .02	± •••	± •••	CHECKED	J.RAUCH	04-APR-2008
			APPROVED	H.CEASE	04-APR-2008
			USED ON	ME-436466	
			MATERIAL	304-SST	

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TEST VESSEL ASSEMBLY
2.53 I.D. REINFORCEMENT PAD

SCALE	DRAWING NUMBER	SHEET	REV
1:1	4900.120-MB-436554	1 OF 1	

CREATED WITH : Ideas12NXSeries GROUP: PPD/MECHANICAL DEPARTMENT

Created: 10:57:44 on 07-04-08 (D-M-Y) By: ellison State: 3-RELEASED

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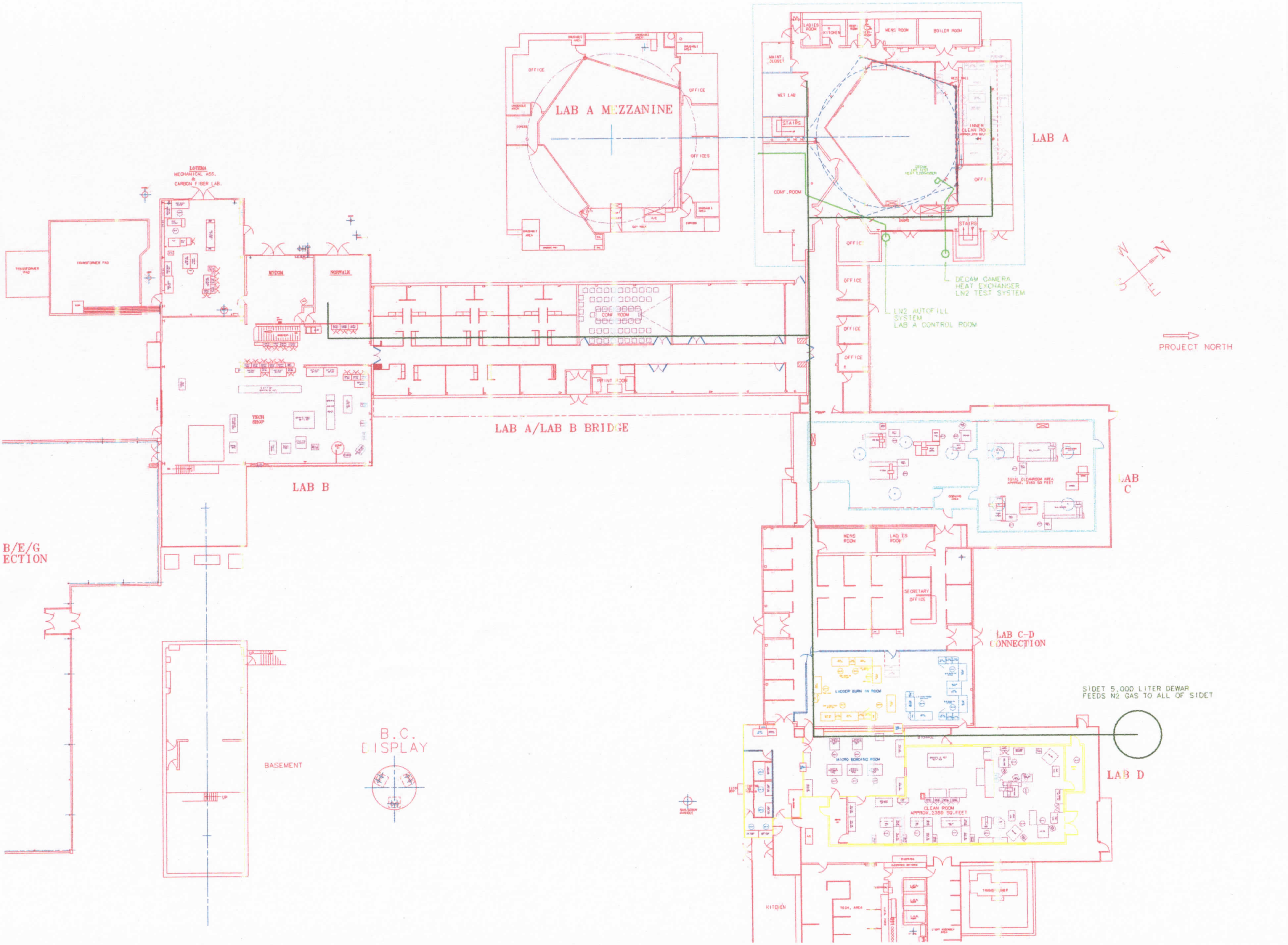
Component DES LN2 TEST
Location LAB A
Date 7/31/08
By Terry Tope

WHAT-IF	CONSEQUENCE/HAZARD	CONCLUSION/RECOMMENDATIONS
Loss of insulating vacuums	System frosts over. Higher heat load to LN2 circuit. Potential for relief valves to open. May cause high consumption of liquid nitrogen.	Safe condition. System is protected with relief valves that vent outdoors. Safe condition. Operational impact.
Loss of instrumentation	May cause system instability with respect to cryostat pressure control or regeneration heater control.	Safe condition. Operational impact.
Power outage occurs at Lab A	All control and instrumentation fails.	Safe condition. Operational impact – Historical values no longer recorded, no pressure control, no cooling flow, relief valves vent.
Leaking stem packing on a cryo valve	Gas will vent into room.	Safe condition (see ODH analysis).
Transfer line inner lines rupture, weld cracks, or silver solder joint breaks	Loss of insulating vacuum and pressurization of the vacuum space.	Safe condition. Gas will vent into room thru vacuum reliefs into room (see ODH analysis).
Weld cracks, bellows break on the vacuum circuit.	Air will fill the vacuum space, thus creating a higher heat load to the cryo circuits.	Safe condition. System is protected with vacuum relief valves.

PLC failure	Pressure control and heater control lost.	Safe condition. Operational impact. LN2 will vent thru relief valves.
A fire at Lab A	Fire detectors go into alarm. Sprinklers open in Lab A. Fire Department dispatched.	
	Likely equipment damage.	
	Fire or water from sprinklers could cause significant damage to controls hardware, wiring, and instrumentation.	Safe condition. Operational problem - Control system not required for system safety but required for operation.
	Superinsulation on piping and vessels could be damaged.	Safe condition. Operational problem - Heat leaks during normal operation would be unacceptable if radiation blankets are damaged.
	Heat input into cryogenic liquids builds pressure in piping and cryostat.	Safe condition. Pressure vessels and piping protected by relief valves (see relief calculations and FMEA). Relief valves vent outside.
	Insulating vacuums may spoil if o-rings are subjected to intense heat.	Safe condition. System is protected with relief valves that vent outdoors. Operational problem - Heat leaks during normal operation would be unacceptable if insulating vacuums are spoiled.
160L stock room dewar tips over	Stock room dewar loses its insulating vacuum and vents gas	Stay clear of stock room dewar relief valve discharge
	Stock room dewar breaks open and vents liquid	If possible, use a wood board to deflect LN2 away from any carbon steel components
Bayonet or transfer line fitting is loose	System will not pressurize prior to operations.	Safe Condition. Operational problem, tighten all transfer line fittings and bayonets.



LAB A MEZZANINE
LAB A
OFFICE
OFFICES
MAINT. CLOSET
WET LAB
STAIRS
CONF. ROOM
LADIES ROOM
KITCHEN
MENS ROOM
BOILER ROOM
INNER CLEAN RO
DECAM CAMERA
HEAT EXCHANGER
LN2 TEST SYSTEM
LN2 AUTOFILL
SYSTEM
LAB A CONTROL ROOM
PROJECT NORTH
LOTEMA
MECHANICAL ASS.
&
CARBON FIBER LAB.
TRANSFORMER PAD
TECH SHOP
LAB A/LAB B BRIDGE
CONF. ROOM
PRINT ROOM
LAB B
B/E/G
ECTION
BASEMENT
B.C.
DISPLAY
LAB C
TOTAL CLEANROOM AREA APPROX. 3160 SQ FEET
MENS ROOM
LADIES ROOM
SECRETARY OFFICE
LAB C-D
CONNECTION
LADDER BURN IN ROOM
SIDET 5,000 LITER DEWAR
FEEDS N2 GAS TO ALL OF SIDET
LAB D
MICRO BONDING ROOM
CLEAN ROOM
APPROX. 2350 SQ.FEET
KITCHEN
TECH. AREA

HAZARD ANALYSIS
DECAM 200L PRESSURE VESSEL
PRESSURE TEST

May 12,2008
Herman Cease

Description of Work:

A pneumatic pressure test of the DECAM 200L pressure vessel will be performed using FESHM 5034. During the pneumatic test, the pressure vessel will have substantial stored energy. Safety precautions are to be taken to mitigate risks associated with the pressure test.

Safety Precautions:
The test will be performed in the gated area outdoors behind MAB. The gated area will be removed of all personnel. The supply manifold is located inside MAB with the roll up door acting as a barrier between the personnel and the vessel.

The Vessel has already been pressure tested by the manufacturing vendor, PHPK and has a documented pneumatic test pressure of 182 psig. The portion of the vessel being tested is the top flange. The top flange is naturally at a higher elevation than the testing personnel and is pointed vertically up away from all other objects.

Prior to testing, the qualified person and the section safety officer will inspect the vessel and check the test setup for safety precautions per ASME Sec. VIII, Div 1, UG-100.

> On welded pressure vessels to be pneumatically tested in accordance with UG-100, the full length of the following welds shall be examined for the purpose of detecting cracks:
> *(a)* all welds around openings;
> *(b)* all attachment welds, including welds attaching nonpressure parts to pressure parts, having a throat thickness greater than 1/4 in. (6 mm).

HAZARDS

Step/Phase of Job	Safety Hazard	Precautions/Safety Procedures
1) Filling the DECAM 200L pressure vessel with nitrogen gas during the pressure test.	Stored Energy. Rapid release of stored energy can cause damage to equipment and personnel.	The vessel will be filled slowly (10% increments) and will be checked for leaks at each increment. If a leak is found, the pressure is immediately reduced by 50% per FESHM 5034
2) Filling the DECAM 200L pressure vessel with nitrogen gas during the pressure test.	Stored Energy. Rapid release of stored energy can cause damage to equipment and personnel.	All personnel will be removed from the area of the test. The vessel is located behind MAB in a gated area. The filling manifold and personnel will be separated from the vessel using the roll up door as a barrier.
3) Filling the DECAM 200L pressure vessel with nitrogen gas during the pressure test.	Stored Energy. Rapid release of stored energy can cause damage to equipment and personnel.	The vessel was pressure tested from the manufacturer. This is a pressure test of the end flange mounted to the pressure vessel. The flange is at a height above personnel and is mounted vertically. The flange points vertically away from all other objects.

Accepted: ______________________________ Date: ____________

Supervisor/Task Manager

Fermilab

Date: May 12, 2008

EXHIBIT B
Pressure Testing Permit*

Type of Test:[]Hydrostatic [X] Pneumatic

Test Pressure: 165 psig **Maximum Allowable Working Pressure**: 150 psig

Items to be Tested
DECAM 200L vessel, previously pressure tested by the manufacturer
DECAM 200L Top flange.

Location of Test: Fermilab MAB **Date and Time** 7/16/08 10 AM

Hazards Involved
Pneumatic stored energy

Safety Precautions Taken

In addition to the items listed below, a JHA has been compiled and a testing procedure.

The test will be performed in the gated area outdoors behind MAB. The gated area will be removed of all personnel. The supply manifold is located inside MAB with the roll up door acting as a barrier between the personnel and the vessel.

The Vessel has already been pressure tested by the manufacturing vendor, PHPK and has a documented pneumatic test pressure of 182 psig. The portion of the vessel being tested is the top flange. The top flange is naturally at a higher elevation than the testing personnel and is pointed vertically up away from all other objects.

Prior to testing, the qualified person and the section safety officer will inspect the vessel and check the test setup for safety precautions per ASME Sec. VIII, Div 1, UG-100.

Special Conditions or Requirements: N/A

HC

Qualified Person and Test Coordinator Herman Cease, PPD/Mech Dept
Date 7/16/08

Division/Section Safety Officer Wayne Schmitt
Dept/Date 7/16/08
PPD/ESH

Results

No visible leaks, Leak checked with Snoop 7/17/08 Herman Cease

Witness Wayne Schmitt
(Safety Officer or Designee)

Dept/Date PPD/ESH 7/16/08

* Must be signed by division/section safety officer prior to conducting test. It is the responsibility of the test coordinator to obtain signatures.

DECAM 200L Pressure Vessel
PRESSURE VESSEL TESTING PROCEDURE
6/16/08, H. Cease

Pressure testing the 200L Vessel for use in the Lab A Test are to follow the following procedures and guidelines. The pressure test will be a pneumatic test.

Overview of the testing procedure:

Test Setup:
The pressure test is performed using nitrogen gas obtained from nitrogen gas bottles. Approximately 1 bottle is required to fill the test vessel and achieve the full test pressure.

The supply manifold has all necessary operating valves and safety relief valves per 5034 Exhibit A. The manifold has a safety relief valve with a cracking pressure equal to 110% the MAWP of the vessel which is 150 psig * 1.10 = 165 psig. The relief valve cracking pressure is checked prior to the pressure vessel test. Relief valve is Anderson Greenwood 83MS66-3 with a capacity of 38scfm air.

Relief valve cracking pressure 165 psig

Safety Precautions:
The test will be performed in the gated area outdoors behind MAB. The gated area will be removed of all personnel. The supply manifold is located inside MAB with the roll up door acting as a barrier between the personnel and the vessel.

The Vessel has already been pressure tested by the manufacturing vendor, PHPK and has a documented pneumatic test pressure of 182 psig. The portion of the vessel being tested is the top flange. The top flange is naturally at a higher elevation than the testing personnel and is pointed vertically up away from all other objects.

Prior to testing, the qualified person and the section safety officer will inspect the vessel and check the test setup for safety precautions per ASME Sec. VIII, Div 1, UG-100.

> On welded pressure vessels to be pneumatically tested in accordance with UG-100, the full length of the following welds shall be examined for the purpose of detecting cracks:
> *(a)* all welds around openings;
> *(b)* all attachment welds, including welds attaching nonpressure parts to pressure parts, having a throat thickness greater than 1/4 in. (6 mm).

Initial Inspection Complete,
7/16/08 Date 7/16/08 Inspector 1 Herman Cease Inspector 2 Wayne Schmitt

Starting the Pressure Test

ASME Sec VIII Div 1 UG-100

The pressure in the vessel shall be gradually increased to not more than one-half of the test pressure. Thereafter, the test pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. Then the pressure shall be reduced to a value equal to the test pressure divided by 1.1 and held for a sufficient time to permit inspection of the vessel. Inspection at the test pressure will be performed visually and using soap bubbles.

Pressure Steps

Step	Hold time	Comments
82 psig	5 minutes	10:19am 12:50
98.5 psig	5 minutes	10:29 am 1:05
115 psig	5 minutes	10:34 Am 110 psi 1:12
131.5 psig	5 minutes	1:28
150 psig	5 minutes	1:34
165psig	5 minutes	1:45
150 psig	As needed for inspection min hold 30 minutes	151psig 1:50 no pressure drop 2:20

If a leak is detected at any pressure level reading during the test, the pressure shall be immediately reduced to one-half that pressure level reading while locating the leak.

If a leak is detected, the vessel and lines shall be depressurized before attempting any repairs or adjustments.

After inspection, the vessel shall be relieved of its pressure gradually through a valve at the test stand.

Final Inspection Complete,
7/17/08 Date Herman Cease Inspector 1 Wayne Schmitt Inspector 2

c	0.3					
d	18.18	inch				
S	16000	psi				
E	1	joint eff				
W	69,385	lbs				
Hg	1.295	inch moment arm				
P	150	psi				
cp/se	0.002813					
1.9WHg/Sed^3	0.001776					
t	1.23					
t class 150	1.56	t - tr =	0.33			
		ID	18.18			
		OD	21			
		area of gasket	86.8	inch^2		
		load	69,385	lbs		
		compression	799.5806	psi		
		# of bolts	16			
		lbs/bolt	4336.6	lbs	5,684	psi
		nut torque	975.7	inch lbs		
			81.3	foot lbs		
		gasket load -operating				
		H	47858			
		Hp	21527			
		W=Wml=H+Hp	69385	lbs		
		B	18.180		inside diameter of flange	
		G	20.160	inch	Diameter at gasket reaction	
		P	150	psi		
		b	0.420	effective gasket surface seating width		
		m	2.7			
		bo	0.705	inch		
		Appendix 2-5				
		Wm2 = bolt load to seat gasket				
		Wm2=3.14*bGy	62,693		seating load ~ operating load	
		y	2359	psi seating stress		

hole #	X_coord	Y_coord	opening diameter inch	Available nozzle wall inch	d inch	reinforcement xsectionarea needed UG-39(b)(2) inc^2	Area available UG-37.1 A1(a) inch^2	Area available UG-37.1 A1(b) inch^2	Area Available A3+A41+A43 inch^2	te	Area available UG-37.1 A5 inch^2	Total area available A1 and A5
1	4.78	-3.26	0.76	0.049	0.662	0.408		1.025	0.112		0.000	1.025
2	5.78	0	0.76	0.049	0.662	0.408		1.025	0.112		0.000	1.025
3	1.11	2.66	0.76	0.049	0.662	0.408		1.025	0.112		0.000	1.025
4	3	0.25	1.335	0.109	1.117	0.688		1.025	0.289		0.000	1.025
5	-6.38	-2.18	2.52	0.12	2.28	1.404		1.025	0.326	0.500	0.615	1.640
6	6	0	2.52	0.12	2.28	1.404		1.025	0.326	0.500	0.615	1.640
7	4.09	4.09	1.25	0	1.26	0.770		1.025	0.000		0.000	1.025
8	-3.45	2.03	2.406	0.154	2.098	1.292		1.025	0.450	0.500	0.672	1.697
9	0	-4.66	4.25	0	4.25	2.617	1.396		0.000	0.500	1.625	3.021
10	6.5	2.68	1.05	0	1.05	0.646		1.025	0.000		0.000	1.025

	between pair distance	2x ave diam
9to4	5.75	5.585
9to1	4.98	4.912
9to8	7.53	6.656
9to5	6.85	2.52
6to8	9.67	4.926
5to8	5.13	4.926
4to1	3.94	2.095
4to3	3.06	2.095
4to2	2.79	2.095
4to8	6.69	3.741
3to8	4.60	3.166
3to6	5.57	3.28
7to10	2.80	2.3

							Stress Nozzle Wall	
							UG-27	
			opening	nozzle		MAWP	Internal Pressure	
hole			diameter	wall	Inner Diam	Nozzle	Circ.	Long.
#	X_coord	Y_coord	inch	inch	inch	psi	t_min (inch)	t_min (inch)
1	4.78	-3.26	0.76	0.049	0.662	150	0.009	0.004
2	5.78	0	0.76	0.049	0.662	150	0.009	0.004
3	1.11	2.66	0.76	0.049	0.662	150	0.009	0.004
4	3	0.25	1.335	0.109	1.117	150	0.015	0.007
5	-6.38	-2.18	2.52	0.12	2.28	150	0.031	0.015
6	6	0	2.52	0.12	2.28	150	0.031	0.015
7	4.09	4.09	1.25	0	1.25			
8	-3.45	2.03	2.406	0.154	2.098	150	0.028	0.014
9	0	-4.66	4.25	0	4.25			
10	6.5	2.66	1.05	0	1.05			

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Particle Physics Division

Mechanical Department Engineering Note

Number: MD-Eng-149 **Date: March 5, 2007**

Project: DECAM

Project Internal Reference: LN2 Testing at Lab A

Title: Trapped Volume Relief Valve Calculations, DECam LN2 Test LabA

Author(s): Herman Cease

Reviewer(s):

Key Words:

Abstract/Summary:

Trapped volume relief valves are sized for the DECam LN2 closed loop cooling system used for the Lab A Test. The required capacity of PRV-6202 is also calculated.

Applicable Codes:

ASME DIVISION I SECTION VIII,

CGA S-1.3 Pressure Relief Design Standards, Part 3 Stationary Storage Containers for Compressed Gasses

Introduction:

Trapped volume relief valves are sized for the DECam LN2 closed loop cooling system used for the Lab A Test. Trapped volume relief valves are located in any section of piping that can be isolated from the rest of the piping system. The largest isolated section of piping is the triple jacketed hose (Part #D010TVJAVCR-720). Two conditions are used to size the relief valve, loss of vacuum and exposure to fire.

The required capacity of PRV-6202 is also calculated.

SV-6311, 6306, 6303, 6408,6200

Trapped volume relief valve

CALCULATIONS

Finding required trapped volume relief capacity using CGA section 5.2.2, pressure relief device flow capacity for loss of vacuum

$$Q_a = \frac{0.383(328-T)}{(922-T)} F \times G_i \times U \times A$$

$$G_i = \frac{73.4(1660-T)}{C \times L} \frac{V_g - V_l}{V_g} \sqrt{\frac{ZT}{M}}$$

Where,

Qa = flow capacity of the relief device cubic meters per hr

F= 1 , correction factor

k=Cp/Cv = 0.538 BTU/Lb.R / 0.256 BTU/Lb.R = 2.1

C = 406 using Table 4 and constant k

L = 69.5 BTU/lb Latent heat at 180 Rankine

Vg =1/ 0.22 lb/ft^3 = 4.5ft^3/lb

Vl = 1/43.1 lb.ft^3 = 0.23 ft^3/lb

Z = 1 Compressibility factor.

T = 100K = 180 Rankine

M = 28 Molecular weight for nitrogen g/mole

U= k/l = overall heat transfer coefficient for 0.25 inch air gap

= 0.0104 BTU/hr.ft.R Air thermal conductivity / 0.02 ft insulation gap

= 0.52 BTU/hr.ft^2.R

A = pipe total exposed surface area, from part number D010TVJAVCR-720

$$A = \pi(0.21ft) \times (65ft)$$

$$A = 43ft^2$$

$$G_i = \frac{73.4(1660-180)}{406 \times 96.5}\left(\frac{4.5-0.23}{4.5}\right)\sqrt{\frac{1 \times 180}{28}} = 6.7$$

$$Q_a = \frac{0.383(328-180)}{(922-180)} 1 \times 6.7 \times 0.52 \times 43ft^2 = 11cfm$$

Finding required capacity using CGA section 5.3.2, pressure relief device flow capacity under emergency conditions including fire.

$$Q_a = F \times G_u \times A^{.82}$$

Where,
Qa = flow capacity of the relief device
F= 1 , correction factor
Gu = 67, Cryogenic Liquid Nitrogen at (150 *1.21)= 181 psi, Gas factor from Table 1 for unisulated container.
A = area of a 10 foot length section of pipe exposed to fire
outer diameter of 2.5 inches. This is the diameter without vacuum jacket.

$$A = \pi(2.5in) \times (120in), \text{from part number D010TVJAVCR - 720}$$

$$A = 942in^2 = 6.6ft^2$$

$$Q_A = (67.0) \times (6.6ft^2)^{.82} = 315\frac{ft^3}{\min}$$

CONCLUSION
A trapped volume relief valve with a minimum capacity of 315 cfm is required.

Circle Seal K5120B-6M-150 valve meets these requirements

PRV-6202-LN
100 PSIG
Pressure Regulating Valve

The pressure regulating valve is used to set the operational condition of the vessel to 100 psig. In the event that the cryo-cooler fails or is unable to keep up with the heat load, the regulating valve opens to vent excess gas build up in the reservoir. The cryocooler capacity is 320 Watts at 80K

The pressure regulating valve is sized to vent gas generated by a 400 Watt system heat load.

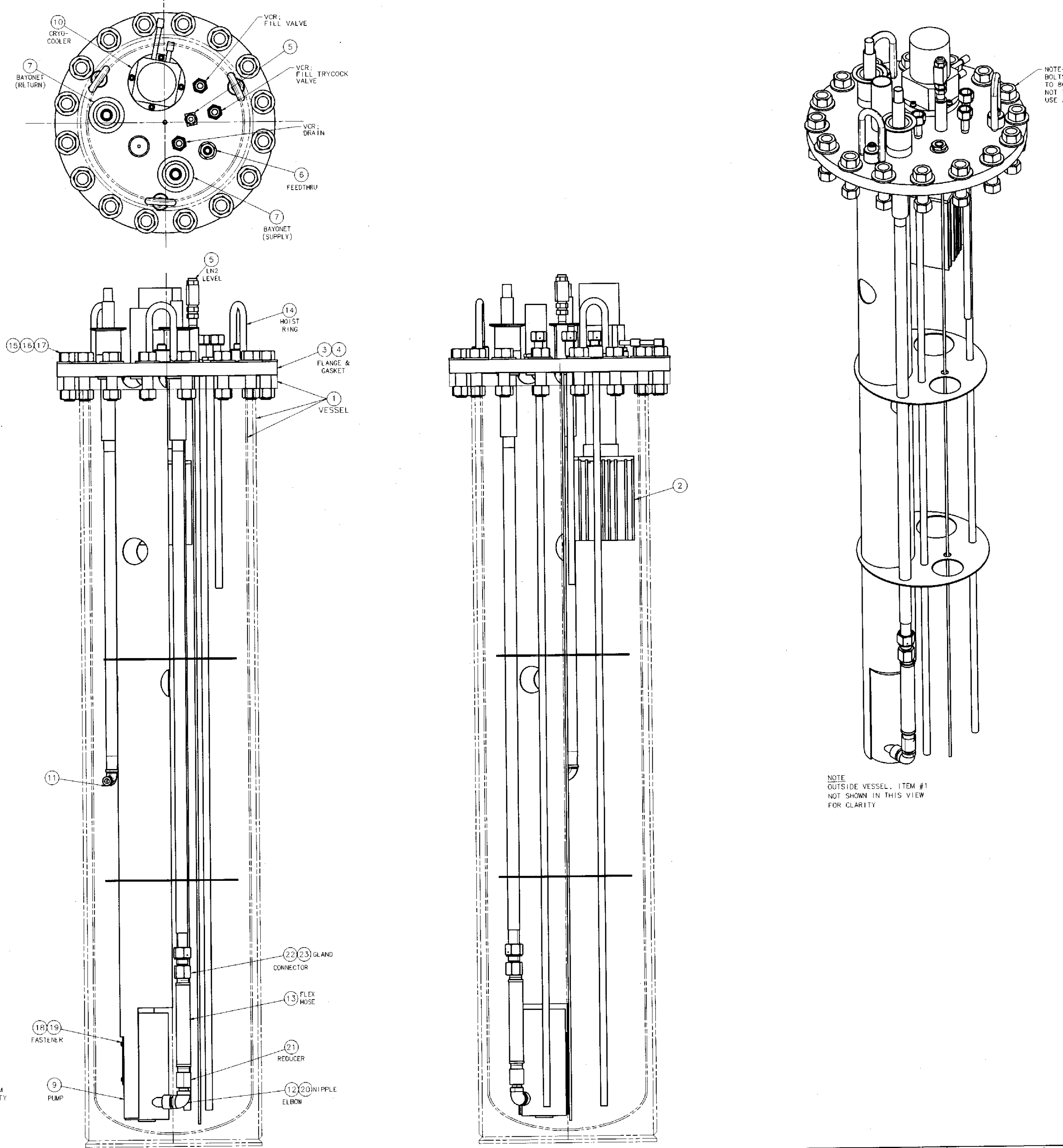
Heat load = 400 J/s * 60s/min * 1 kJ/1000 J = 24 kJ/min
Latent Heat of vaporization = 161 kJ/kg

Amount of Nitrogen Vaporized = 24 kJ/min / 161 kJ/kg = 0.15 kg/ min

Density of Nitrogen at (100 psi/ 14.7 psi) 6.8 atmospheres = 3.484 kg/m^3 * 6.8 = 23.7 kg/m^3

Amount of Nitrogen Vaporized = 0.15 kg/ min / 23.7 kg/m^3 = 6.3e-3 m^3/min = 0.15 cfm

Conclusion:
A pressure regulating valve with a minimum capacity of 0.15 cfm is required to keep up with the heat load in the event that the cryo-cooler cannot.



REV	DESCRIPTION	DRAWN / APPROVED	DATE

NOTES
(UNLESS OTHERWISE SPECIFIED)

1. DRAWING TO BE INTERPRETED PER ASME Y14.100-2000.
2. ALL WELDS TO BE VACUUM LEAK TIGHT. LEAK TEST: NO LEAK SHALL BE DETECTABLE ON THE MOST SENSITIVE SCALE OF A HELIUM LEAK DETECTOR WITH A MINIMUM SENSITIVITY OF 10 ATM.CC/SEC.
3. APPROX. WEIGHT OF ASSEMBLY = 830 LBS.

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
23	SWAGELOK P/N SS-16-VCR-2-VS	VCR FACE SEAL FITTING, SWAGELOK 1" UNPLATED GASKET, 316SS	1
22	SWAGELOK P/N SS-16-VCR-7-16	VCR FITTING, SWAGELOK FEMALE NPT 1" VCR, 316SS	1
21	McMASTER-CARR P/N 4464K375	REDUCING UNION, 3/4 FPT x 1"FPT, 304 SST	1
20	McMASTER-CARR P/N 4830K191	PIPE NIPPLE, 3/4 MPT x 3/4 MPT, 304 SST, (1.38 LG.)	2
19	COML.	WASHER, LOCK, 5/16 SCREW, SST	4
18	COML.	SCREW, SOCKET HEAD CAP, 5/16-18 UNC-2B x 2.00 LG., SST	4
17	COML.	WASHER, FLAT, 1.125 SCREW, SST	16
16	COML.	NUT, ASME HEX, 1.125-7 UNC-2B, ASTM A194 GRADE 8, SST	16
15	COML.	SCREW, ASME HEX HD CAP, 1.125 7 UNC-2B x 5.00 LG., SST, ASTM A193 GRADE B8 CL1	16
14	McMASTER-CARR P/N 2949T33	HOIST RING, 1/2-13, 1250 LB, SST	3
13	GRAINGER P/N G1005M120	FLEXIBLE METAL HOSE, ø1.00 x 12.00, SCH.40, NPT FITTINGS, 304 SST	1
12	McMASTER-CARR P/N 4464K39	THREADED ELBOW, 3/4" NPT, 90° MALE x 90° FEMALE, 304 SST	1
11	McMASTER CARR P/N 4464K41	STREET ELBOW, 1" NPT, 304SST	1
10	CRYOMECH, INC.	CRYOCOOLER, CRYOMECH, INC. CH10300, COLDHEAD	1
9	BARBER-NICHOLS	PUMP, SUBMERSIBLE CRYOGENIC TRANSFER; 3.5 GPM, #BNLNG-01-000	1
8			
7			
6	PAVE TECH. P/N VS15-AL	FEEDTHROUGH CONN., HERMETIC, SEAL, BULKHD. #VS15-AL-150-20-1E22-48-48	1
5	TERAGON RES. P/N LP7	LN2 LEVEL TRANSMITTER, INSERT. LG.=92.00", SENSING LG.=64.00" TERAGON RESEARCH P/N LP7	1
4	McJUNKIN P/N 2436-7704	RING GASKET, ø18.00 x 1/16 THK 150 LB., DURABLA #8500	1
3	ME-436466	TOP FLANGE WELDMENT	1
2	MC-436427	HEAT EXCHANGER ASSEMBLY	1
1	01-1963-6500	PHPK 200L VESSEL	1

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
.XX	.XXX	ANGLES	ORIGINATOR	H.CEASE	31-JUL-2007
± .02	± ---	± ---	DRAWN	P.POLL	05-SEP-2007
			CHECKED	J.RAUCH	05-MAR-2008
			APPROVED	H.CEASE	05-MAR-2008
			USED ON		
			MATERIAL	SEE PARTS LIST ABOVE	

1. BREAK ALL SHARP EDGES .../ MAX.
2. DO NOT SCALE DRAWING
3. DIMENSIONS BASED UPON ASME Y14.5M-1994
4. MAX. ALL MACH. SURFACES
5. DRAWING UNITS: U.S. INCH

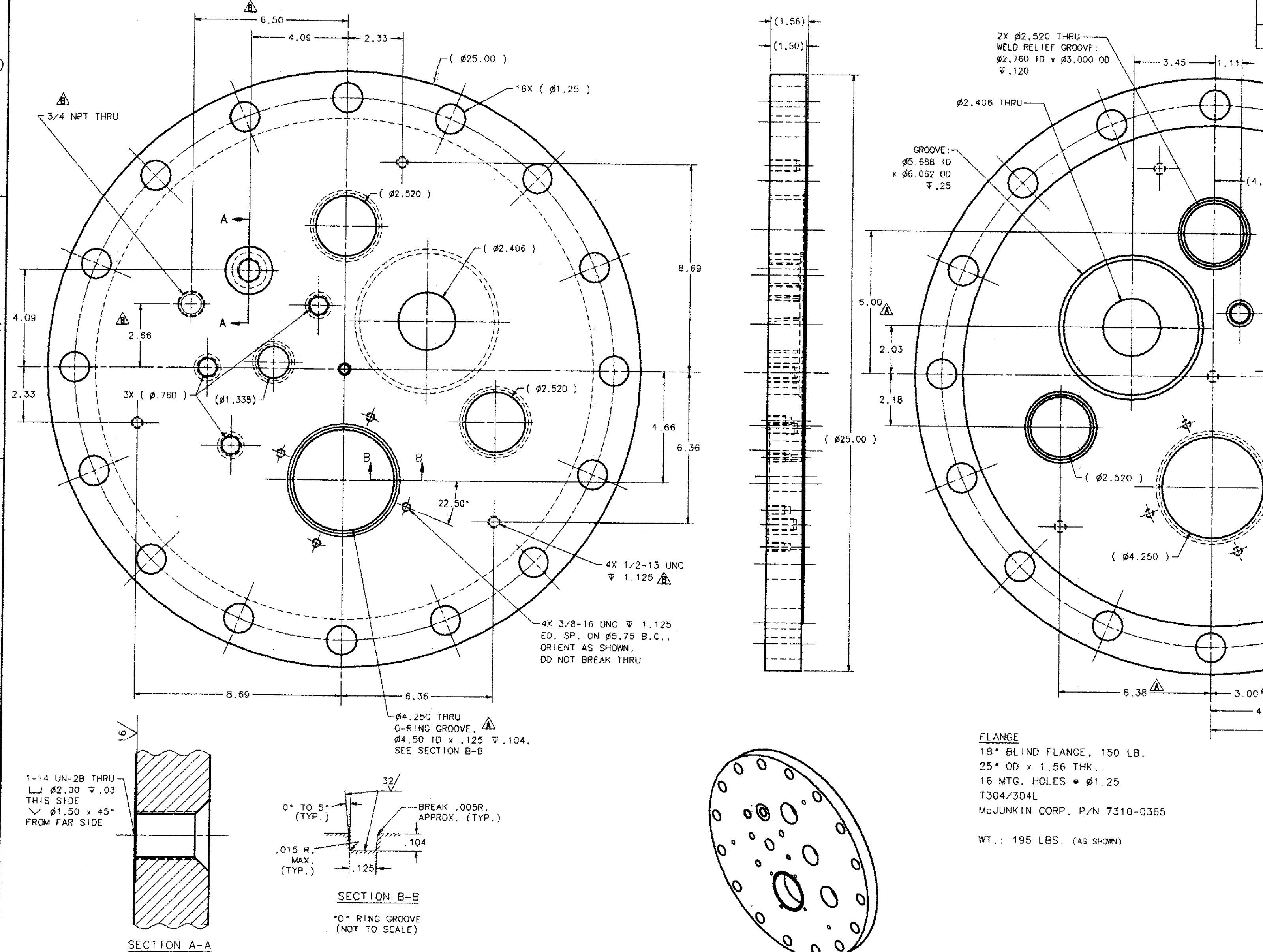
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

DECAM/CCDS
TEST VESSEL ASSEMBLY
TEST VESSEL DEWAR ASSEMBLY

SCALE	DRAWING NUMBER	SHEET	REV
1:4	4900.120-ME-436426	1 OF 1	

CREATED WITH: IdeasI2NXSeries | GROUP: PPD/MECHANICAL DEPARTMENT

REV	DESCRIPTION	DRAWN / APPROVED	DATE
A	REV. DIM.: Ø4.25, WAS Ø4.00; 6.00, WAS 5.78; 6.38, WAS 6.17; MOVED Ø1.335: 3.00, WAS 2.88;	PAT POLL / HERMAN CEASE	02/06/08 / 02/06/08
B	ADDED 1/2-13 HOLE AT CENTER, TOTAL=4; ADDED 3/4 NPT.	PAT POLL/B.ELLISON / HERMAN CEASE	2/25/08 / 04/07/08



FLANGE
18" BLIND FLANGE, 150 LB.
25" OD x 1.56 THK.
16 MTG. HOLES Ø1.25
T304/304L
McJUNKIN CORP. P/N 7310-0365

WT.: 195 LBS. (AS SHOWN)

UNLESS OTHERWISE SPECIFIED		
ORIGINATOR	H.CEASE	31-JUL-2007
DRAWN	P.POLL	05-SEP-2007
CHECKED	J.RAUCH	24-JAN-2008
APPROVED	H.CEASE	24-JAN-2008
USED ON	ME-436486	
MATERIAL	SEE NOTE	

.XX ± .02 ; .XXX ± .005 ; ANGLES ± .25°
1. BREAK ALL SHARP EDGES .015 MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS BASED UPON ASME Y14.5M-1994
4. MAX. ALL MACH. SURFACES 125
5. DRAWING UNITS: U.S. INCH

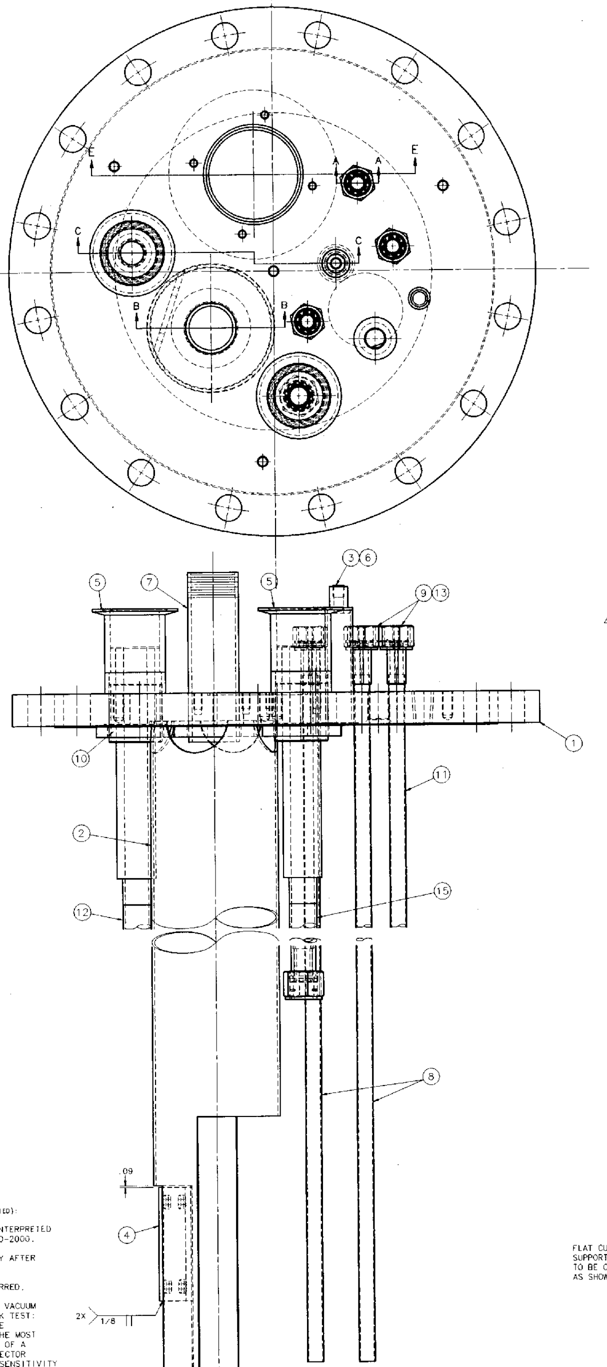
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

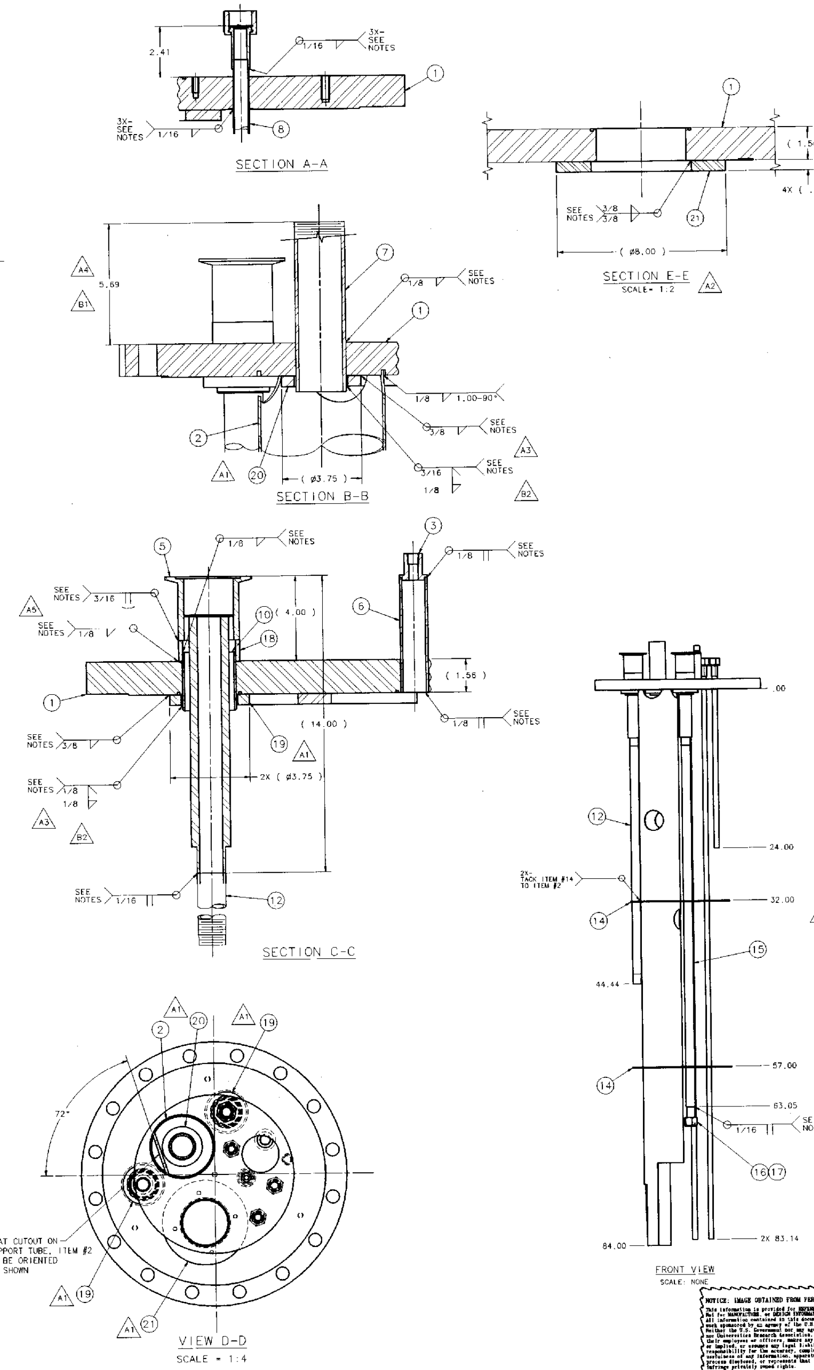
DECAM/CCDS
TEST VESSEL ASSEMBLY
TOP FLANGE

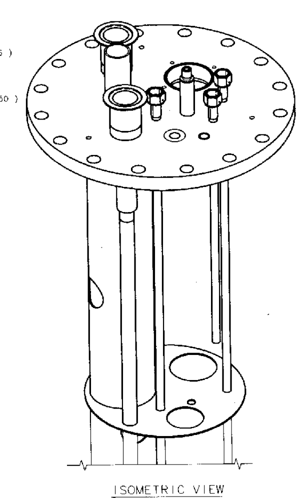
SCALE	DRAWING NUMBER	SHEET	REV
1:4	4900.120-MD-436428	1 OF 1	B

CREATED WITH: Ideas12NXSeries GROUP: PPD/MECHANICAL DEPARTMENT

Created: 14:53:09 on 07-04-08 (D-M-Y) By: ellison State: 3-RELEASED







REV	DESCRIPTION	DRAWN / APPROVED	DATE
A	1. ADDED ITEMS 19,20 & 21; 2. ADDED SECTION E-E; 3. ADDED WELDS. 4. CHNGD. LENGTH ITEM 10, 2.50 WAS 2.25;DIM. 5.94 WAS 6.19; 5. CHANGED WELD SYMBOL	B.ELLISON / H.CEASE	04-APR-2008 / 07-APR-2008
B	1. CHANGED DIM.: 5.69 WAS 5.94; ITEM 10 LGNTH. 2.75 WAS 2.50. 2. CHANGED WELD SYMBOLS.	B.ELLISON / H.CEASE	09-APR-2008 / 09-APR-2008

NOTES
(UNLESS OTHERWISE SPECIFIED):

1. DRAWING TO BE INTERPRETED PER ASME Y14.100-2000.
2. DIMENSIONS APPLY AFTER ALL FINISHING.
3. PART TO BE DEBURRED.
4. ALL WELDS TO BE VACUUM LEAK TIGHT. LEAK TEST: NO LEAK SHALL BE DETECTABLE ON THE MOST SENSITIVE SCALE OF A HELIUM LEAK DETECTOR WITH A MINIMUM SENSITIVITY OF 10^{-9} ATM.CC/SEC.

	ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
A1	21	MB-436552	4.75 I.D. REINFORCEMENT PAD	1
A1	20	MB-436554	2.53 I.D. REINFORCEMENT PAD	1
A1	19	MB-436553	2.65 I.D. REINFORCEMENT PAD	2
	18	MB-436542	BAYONET WELD BOSS COLLAR	2
	17	SWAGELOK P/N SS-16-VCR-1	VCR FITTING, SWAGELOK FEMALE NUT 1" VCR, 316SS	1
	16	SWAGELOK P/N SS-16-VCR-3	VCR FITTING, SWAGELOK GLAND, 1" VCR, SOCKET WELD, 316L	1
	15	COML.	PIPE, 1" NOM. SCH.10 x 54.62 LG., SST	1
	14	MB-436431	SPACER	2
	13	SWAGELOK P/N SS-12-VCR-1	VCR FITTING, SWAGELOK FEMALE NUT 3/4" VCR, 316SS	3
	12	COML.	PIPE, 1" NOM., SCH.10, SST x 36.00 LG., MPT ● ONE END	1
	11	COML.	TUBING, ø3/4", #18 Ga. (.049) x 24.00 LG., SST	1
B1 A4	10	COML.	TUBE, ø2.50 OD x .120 WALL x 2.75 LG., 304 SST	2
	9	SWAGELOK P/N SS-12-VCR-3	VCR FITTING, SWAGELOK GLAND, 3/4" VCR, SOCKET WELD, 316L	3
	8	COML.	TUBING, ø3/4", #18 Ga. (.049) x 85.50 LG., SST	2
	7	COML.	PIPE, 2" NOM., SCH.40 x 8.00 LG., SST, MPT ● ONE END ON OUTSIDE	1
	6	COML.	LVT VACUUM SHELL PIPE, ø1.00 x SCH.10 x 5.42 LG., 304 SST	1
	5	PBF-10	PB FEMALE COUPLING, 1 x 2 1/2 BAYONET, 304 SST, PHPK TECH.	2
	4	MB-436538	TRANSFER PUMP MOUNTING PLATE	1
	3	MB-436434	TOP FLANGE STANDOFF	1
	2	MC-436467	SUPPORT TUBE, ø6.00	1
	1	MD-436428	TOP FLANGE	1

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
.XX ± .02	.XXX ± ---	ANGLES ± 1°	ORIGINATOR	H.CEASE	31-JUL-2007
			DRAWN	P.POLL	30-JAN-2008
			CHECKED	J.RAUCH	26-FEB-2008
			APPROVED	H.CEASE	26-FEB-2008

1. BREAK ALL SHARP EDGES .015 MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS BASED UPON ASME Y14.5M-1994
4. MAX. ALL MACH. SURFACES 125
5. DRAWING UNITS: U.S. INCH

USED ON: ME-436426

MATERIAL: SEE PARTS LIST ABOVE

NOTICE: IMAGE OBTAINED FROM FERMILAB WEB SITE
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FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

DECAM/CCDS
TEST VESSEL ASSEMBLY
TEST VESSEL WELDMENT

SCALE	DRAWING NUMBER	SHEET	REV
1:1	4900.120-ME-436466	1 OF 1	B

CREATED WITH : Ideas12NXSeries | GROUP: PPD/MECHANICAL DEPARTMENT

TEAM® Industrial Services, Inc.

RADIOGRAPHIC INSPECTION REPORT (Gamma)

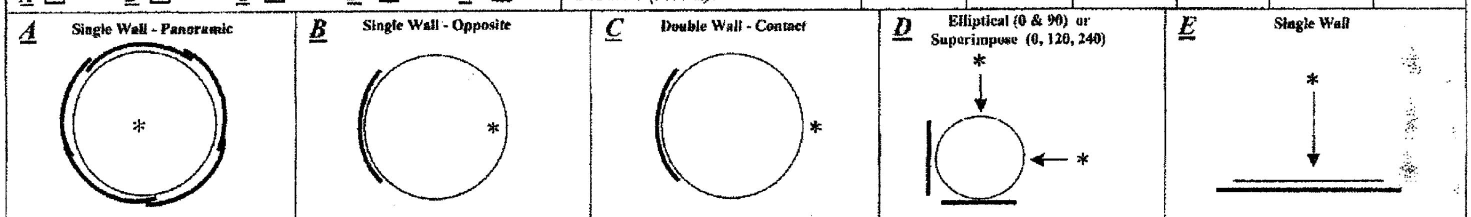
TEAM Industrial Services
3640 West 179TH Street
Hammond, IN. 46323
(219) 838-0505 Fax#:-8558

Form: 20.1 – 212, Rev 2

Customer: FERMILAB	Location: 3640 W 179th HAMMOND, IN	WO No.: 10388054
Specification: ASME SEC IX	Acceptance Std: ASME B31.3	TEAM Procedure: RT. ASME. 1

Radiation Source Type: IR-192 ☒ Co-60 ☐	Source Strength: 18 CI	Effective Focal Spot Size: .148"	Film to Source Distance (SFD): 20"	Exposure Time: 9 MIN
Pipe Diameter: .75"	Plate Thickness: N/A	Weld Thickness: .083" +Reinf.	Joint Type: BUTT	Material Type: S/S
Penetrameter: (Type / Size) ASTM 12	Material Type: S/S	Penetrameter Location: Source Side ☒ Film Side ☐	Shim Mat'l: S/S	Shim Thickness: .250"
Film Type: KODAK MX	Film Size: 4.5" x 10"	Film Emulsion #: 234 003	Film Exp.: 4/2010	Film Technique: Single ☒ Multiple ☐ — Film Processing: Manual ☒ Automatic ☐

Exposure Arrangement: A ☐ B ☐ C ☐ D ☒ E ☐	Intensifying Screens (Mat'L): Pb	Front: .010 Center: —	Back: .010



EXPOSURE NO.	WELD NO.	VIEW	"UG"	Original or Repair	ACCEPT	REJECT	Porosity	Slag or Inclusion	Tungsten Inclusion	Incomplete Fusion	Inadequate Penetration	Crack	Root Concavity	Root Convexity	Undercut	Film Artifact	Remarks	Penetrameter Density	Weld Density
	W-4	0	≤ .02	O	/													2.0/4.0	2.0/4.0
		120			/														
		240			/														
	W-5	0			/														
		120			/														
		240			/														

Inspector: PRINT SIGNATURE [signature] Level: ~~II~~ III Date: 7.31.08

TEAM Industrial Services, Inc.

RADIOGRAPHIC INSPECTION REPORT (Gamma)

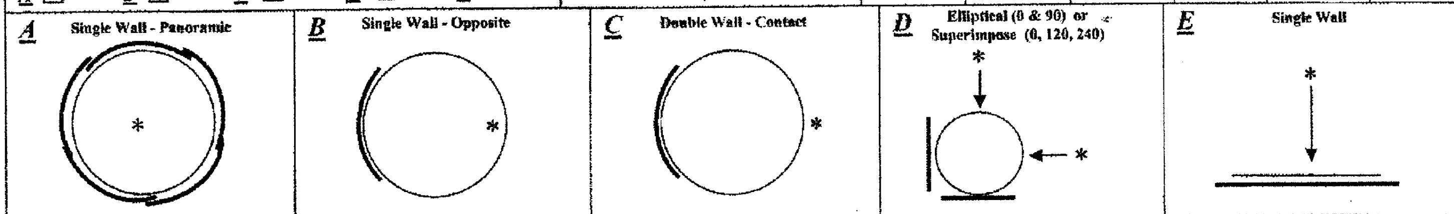
TEAM Industrial Services
3640 West 179TH Street
Hammond, IN. 46323
(219) 838-0505 Fax#:-8558

Form: 20.1 – 212, Rev 2

Customer: FERMILAB	Location: 3640 W 179th HAMMOND IN	WO No.: 10388054
Specification: ASME SEC IX	Acceptance Std: ASME B31.3	TEAM Procedure: RT.ASME.1

Radiation Source Type: IR-192 ☒ Co-60 ☐	Source Strength: 18 Ci	Effective Focal Spot Size: .148"	Film to Source Distance (SFD): 20"	Exposure Time: 9 MIN
Pipe Diameter: 1.5"	Plate Thickness: N/A	Weld Thickness: .109" +Reinf.	Joint Type: BUTT	Material Type: S/S
Penetrameter: (Type / Size) ASTM #12	Material Type: S/S	Penetrameter Location Source Side ☒ Film Side ☐	Shim Mat'l: S/S	Shim Thickness: .250"
Film Type: KODAK MX	Film Size: 4.5" x 10"	Film Emulsion #: 234 603	Film Exp.: 11/2010	Film Technique Single ☒ Multiple ☐
Film Processing Manual ☒ Automatic ☐				

Exposure Arrangement: A ☐ B ☐ C ☐ D ☒ E ☐	Intensifying Screens (Mat'L):	Pb	Front	.010	Center	—	Back .010



EXPOSURE NO.	WELD NO.	VIEW	"UG"	Original or Repair	ACCEPT	REJECT	Porosity	Slag or Inclusion	Tungsten Inclusion	Incomplete Fusion	Inadequate Penetration	Crack	Root Concavity	Root Convexity	Undercut	Film Artifact	Remarks	Pnentrameter Density	Weld Density
	W-2	0	≤.02	O	/													2.0/4.0	2.0/4.0
		120			/														
		240			/														
	W-3	0			/														
		120			/														
		240			/														
	W-6	0			/		/												
		120			/														
		240			/														
	W-7	0			/														
		120			/														
		240			/														

PRINT SIGNATURE

Inspector: [signature] Level: ~~II~~ III Date: 7-31-08

TEAM Industrial Services, Inc.

RADIOGRAPHIC INSPECTION REPORT (Gamma)

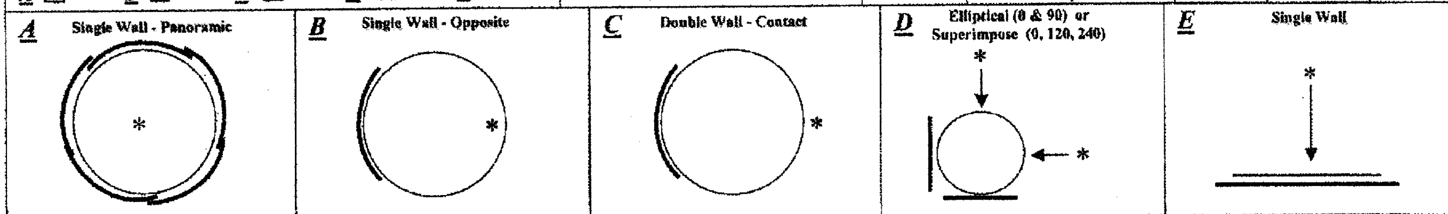
TEAM Industrial Services
3640 West 179TH Street
Hammond, IN. 46323
(219) 838-0505 Fax#:-8558

Form: 20.1 – 212, Rev 2

Customer: FERMILAB	Location: 3640 W. 179th HAMMOND, IN	WO No.: 10388054
Specification: ASME SEC IX	Acceptance Std: ASME B31.3	TEAM Procedure: RT. ASME. I

Radiation Source Type: IR-192 ☒ Co-60 ☐	Source Strength: 18 CI	Effective Focal Spot Size: .148"	Film to Source Distance (SFD): 20"	Exposure Time: 9 MIN
Pipe Diameter: 1"	Plate Thickness: N/A	Weld Thickness: .109" +Reinf.	Joint Type: BUTT	Material Type: S/S
Penetrameter: (Type / Size) ASTM 12	Material Type: S/S	Penetrameter Location Source Side ☒ Film Side ☐	Shim Mat'l: S/S	Shim Thickness: .250"
Film Type: KODAK MX	Film Size: 4.5" X 10"	Film Emulsion #: 234 003	Film Exp.: 11/2010	Film Technique Single ☒ Multiple ☐
Film Processing Manual ☒ Automatic ☐				

Exposure Arrangement:	Intensifying Screens (Mat'L): Pb	Front	Center	Back
A ☐ B ☐ C ☐ D ☒ E ☐		.010	—	.010



EXPOSURE NO.	WELD NO.	VIEW	"UG"	Original or Repair	ACCEPT	REJECT	Porosity	Slag or Inclusion	Tungsten Inclusion	Incomplete Fusion	Inadequate Penetration	Crack	Root Concavity	Root Convexity	Undercut	Film Artifact	Remarks	Penetrameter Density	Weld Density
	W-1	0	≤.02	O	/													2.0/4.0	2.0/4.0
		120			/														
		240			/														
	W-8	0			/														
		120			/														
		240			/														

PRINT SIGNATURE

Inspector: [signature] Level: ~~II~~ III Date: 7.31.08

Fermilab

DES Lab A LN2 Test
Operating Procedures

Rev	Date	Description	Originated by	Approved by
None	Aug 7, 2008	Original issue	T. Tope H. Cease	

Reviewed by: ______________________

Date: ______________________

DES Lab A LN2 Test
Operating Procedures

Table of Contents

DES Lab A LN2 Test
Operating Procedures

1.0 Introduction

The Lab A LN2 System is used to perform preliminary tests of the cooling system and to cool the Multi-CCD Test Vessel. The MCCDTV is a prototype camera vessel for the Dark Energy Survey Camera. The LN2 reservoir and valvebox are located outside lab A. A triple jacketed hose that contains supply, return and vacuum jacket is used a transfer line from the valve box to the heat exchanger inside Lab A. The heat exchanger is a simple tube heat exchanger and is used to cool the MCCDTV.

2.0 Flow Schematic

The flow schematic for the cryostat is shown in Figure 2.1. The flow schematic is also available at http://des-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=1537 as "Process and Instrument Diagram - ME-436389REVA". Valves and instruments are referenced by number in the operating procedures.

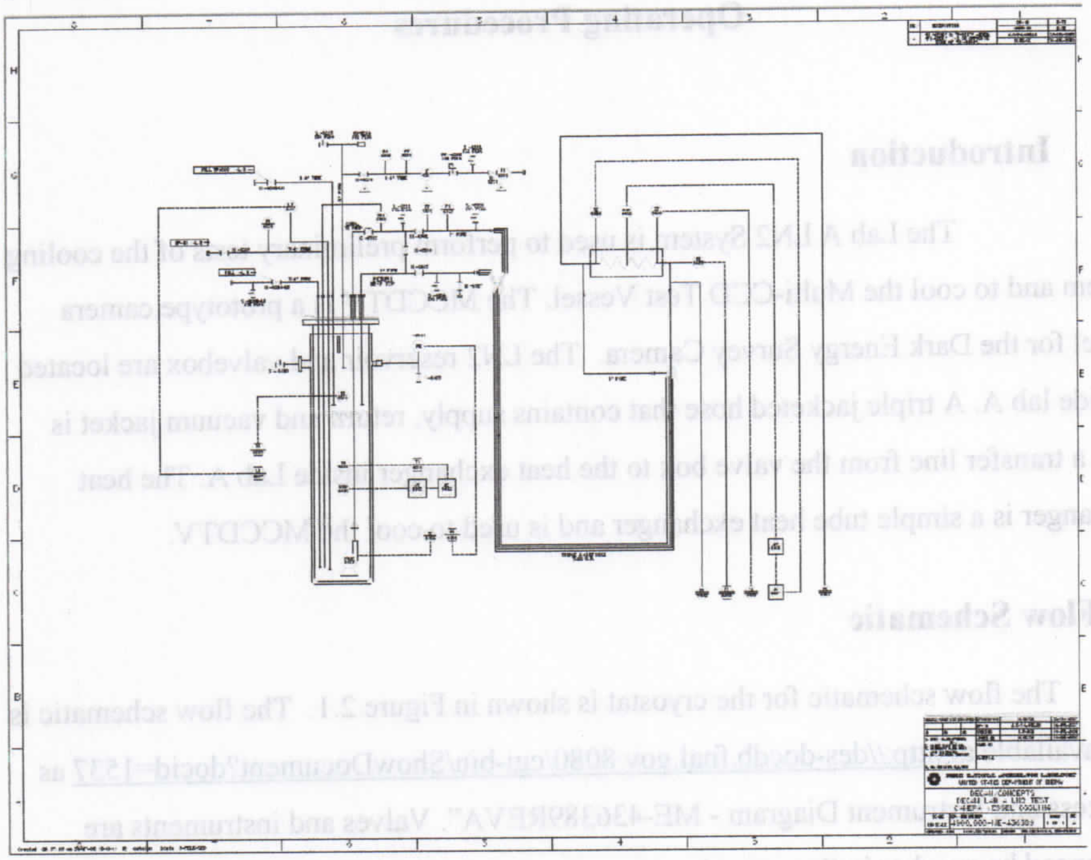


Figure 2.1: DECAM Lab A LN2 test flow schematic.

3.0 Required Training Prior to Operating the System

A general overview of the Lab A LN2 Test system and familiarity with the FESHM chapters are required prior to operating the system. A general overview can be obtained with on the job training and reviewing all of the documents associated with the cryogenic safety review which can be obtained at http://des-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=1537 or near the Lab A LN2 Test controls desk.

As described in FESHM 5032 "Cryogenic personnel should attend the Fermilab safety courses, "Oxygen Deficiency Hazards," "Cryogenic Safety" and "Pressurized Gas Safety" or their equivalents. Other courses, as described in Chapters 4010 and 4030, may also be appropriate. General training in cryogenic principles may also be beneficial, particularly to personnel involved in operations."

FESHM 5031, Pressure Vessels, includes a general description of what requirements are expected of a system that contains a pressure vessel. The operator should be familiar with the information contained within FESHM 5031.

FESHM 5101, **Personal Protective Equipment (PPE)**, outlines protective equipment needed while working with cryogens. Cryogenic gloves and a full face shield shall be worn at all times while operating manual valves or working around the safety relief devices. Long pants and closed toe shoes are recommended while working with cryogenics.

Before any of the following procedures are performed, get training from a person experienced with the complete system.

4.0 Fill Procedure

The 200L Vessel is filled using 160L portable dewars. Station the 160L dewar near the fill line on the 200L vessel. The first time the 200L vessel is filled, two 160L dewars are needed to completely fill the system.

Prior to performing a fill,

Don face shield, and cryogenic gloves.

Check that the 160L fill dewar is pressurized above 200psig,

Attach an all metal transfer line with the proper flare fittings, and have wrenches available to tighten the fittings.

1) Open fill valve MV-6204
2) Open Fill try-cock valve MV-6208
3) Slowly open the valve on the 160L dewar to start transferring liquid into the 200L vessel Note: The 200L is full when liquid vents from the fill try-cock valve.
4) Slowly close the valve on the 160L dewar .
5) Close fill valve MV-6204.
6) Close fill try-cock valve MV-6208.
7) Wait a few minutes, using the wrenches slowly open the flare fittings and remove the transfer line.

5.0 Drain Procedure

When the cooling system is stopped, most of the liquid drains back into the 200L vessel. If maintenance is needed on the vessel, the liquid is drained from the system.

Prior to draining the dewar, don face shield, cryogenic gloves. The fog produced when venting the vessel is extremely cold and creates a low oxygen pressure area. Ensure that this operation takes place slow enough that a hazard is not created.

1) Slowly open the fill try-cock valve MV-6208 to vent excess pressure from the 200L vessel.
2) Slowly open valve MV-6205 and let the liquid vent from the vessel. MV-6208 is also used to control the pressure in the dewar and the venting rate.
3) When all of the liquid has been vented, close valves MV-6205 and MV-6208.

6.0 Heat Exchanger Cool Down Procedure

This procedure is used to cool down all of the piping in the system prior to operations. The 200L vessel is pressurized, liquid from the vessel is then pushed thru the piping system. The boil-off gas is vented using MV-6307. Prior to operating manual valves, don face shield, and cryogenic gloves.

1) Close valves MV-6307, 6208, 6205, 6204, 6310, 6302, 6303.
2) Open valves MV-6216, 6201.
3) Let the system pressurize to the normal operating pressure, pressure can be built up using heater 6102 and setting the set-point on TE-6211 to 100K.
4) Slowly Open return line vent valve MV-6307 and allow the piping system to cool down. Approximately 20 Liters are needed to boil-off to cool all of the piping down.
5) Once the system is cold, slowly open MV-6303 and close MV-6307

7.0 Liquid Circulation Start up

Liquid circulation can start up once the system has been pressurized and cooled down. The pump is initially started by circulating all of the liquid thru the bypass valve MV-6310. Once the pressure stabilizes in the 200L vessel then liquid can slowly be circulated through the rest of the piping system until full design flow is achieved. The heater in the heat exchanger is not used until the full design flow is achieved. Prior to operating manual valves, don face shield, and cryogenic gloves.

1) Pressurize the system and cool down all of the piping using the Cool Down Procedure.
2) Close valves MV-6302, 6307, Valve MV-6303 is left open ¼ turn so that a trapped volume in the piping system is not created
3) Open control valve MV-6310 half way
4) Slowly start pump 6103, increase speed until design flow rate is achieved. Confirm flow rate using PDI-6313 and the pump flow curve.
5) Slowly open valve MV-6302
6) Once the pressure in the vessel has stabilized, slowly open valve MV-6303
7) Adjust flow rate to the design flow rate using control valve MV-6310 and confirming the flow rate using FT-6301 and PDI-6313.
8) Once the flow rate and pressure in the vessel are stable, the heat exchanger can be operated.

8.0 Abnormal Conditions Procedures

Small leak, Alert other people, Evacuate area,

Large Leak, Alert other people, Evacuate area, call safety -3131

Dewar failure, Alert other people, Evacuate area, call safety -3131

Fermilab

DES Lab A LN2 Test
Piping System Engineering Note

Rev	Date	Description	Originated by	Approved by
None	Aug 11, 2008	Original issue	T. Tope H. Cease	

Reviewed by: ______________________

Date: ______________________

DES Lab A LN2 Test
Piping System Engineering Note

Table of Contents

DES Lab A LN2 Test
Piping System Engineering Note

Introduction

This document constitutes the Piping System Engineering Note for the cryogenic piping associated with the DES Lab A LN2 test.

The pipe descriptions and a table summary of the operating parameters are shown in Table 1.1.

Table 1.1: Cryogenic piping description and summary

Description	Fluid	OD (in)	ID (in)	$P_{operating}$ (psid)	P_{max} (psid)	Temp (K)
U-tube LN2 piping 1 in. SCH 40 pipe (vacuum jacketed)	LN2	1.315	1.049	115	165	100
Drain Line, Fill Trycock Line, and Fill Line for the DES pressure vessel ¾ in. OD tube	LN2	0.750	0.652	100	150	100
Vent line	GN2	0.250	0.180	100	150	> 100
Cooling Ring ¾ in. SCH 10 pipe	LN2	1.050	0.884	100	150	100
Cooling Ring ¾ in. OD tube	LN2	0.7500	0.666	100	150	100
Valve Box (numerous components)	LN2	*	**	100	150	100

*The largest diameter piece of piping in the valve box is 1 inch pipe.
**The thinnest pipe wall thickness in the valve box is 0.065 inches.

2.0 Flow schematic

The flow schematic for the cryostat is shown in Figure 2.1. The flow schematic is also available at http://des-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=1537 as "Process and Instrument Diagram - ME-436389REVA".

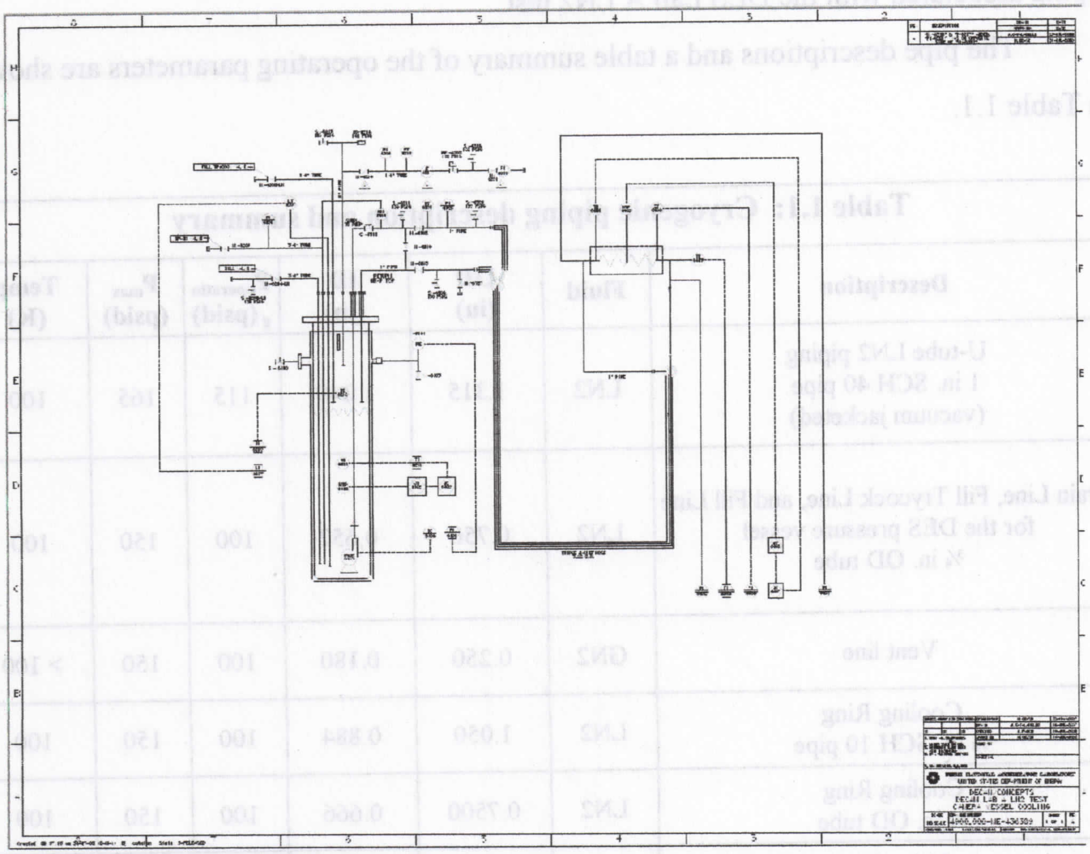


Figure 2.1: DECAM Lab A LN2 test flow schematic.

A schematic of the piping layout at Lab A is shown in figure 2.2 The 200L vessel, instrument lines, all relief valves, and the valve box are located outside at Lab A. The triple jacket hose is used as a transfer line to the camera heat exchanger which is located inside Lab A under the dome.

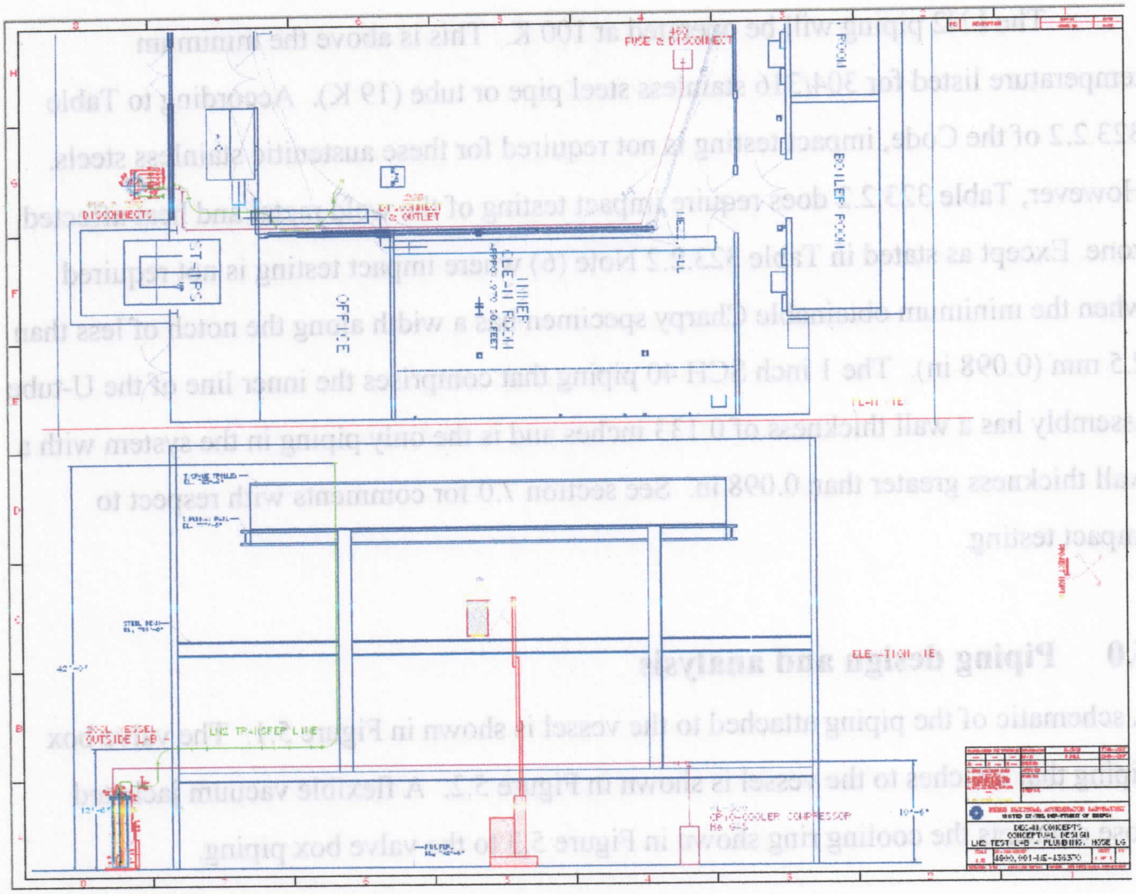


Figure 2.2: DECAM Lab A LN2 test piping schematic.

3.0 Design codes and evaluation criteria

The DES Lab A LN2 Test piping must meet all of the requirements of Section 5031.1 of the Fermilab ES&H Manual. This section states that piping systems containing cryogenic fluids fall under the category of Normal Fluid Service and shall adhere to the requirements of the ASME Process Piping Code B31.3.

4.0 Materials

The piping is fabricated from 304/304L and 316/316L stainless steel tube and pipe. The allowable stress used in this document is 16,700 psi, which is the lowest value listed for these pipe and tube materials in B31.3 Appendix A.

The LN2 piping will be operated at 100 K. This is above the minimum temperature listed for 304/316 stainless steel pipe or tube (19 K). According to Table 323.2.2 of the Code, impact testing is not required for these austenitic stainless steels. However, Table 323.2.2 does require impact testing of the weld metal and heat affected zone. Except as stated in Table 323.2.2 Note (6) where impact testing is not required when the minimum obtainable Charpy specimen has a width along the notch of less than 2.5 mm (0.098 in). The 1 inch SCH 40 piping that comprises the inner line of the U-tube assembly has a wall thickness of 0.133 inches and is the only piping in the system with a wall thickness greater than 0.098 in. See section 7.0 for comments with respect to impact testing.

5.0 Piping design and analysis

A schematic of the piping attached to the vessel is shown in Figure 5.1. The valve box piping that attaches to the vessel is shown in Figure 5.2. A flexible vacuum jacketed hose connects the cooling ring shown in Figure 5.3 to the valve box piping.

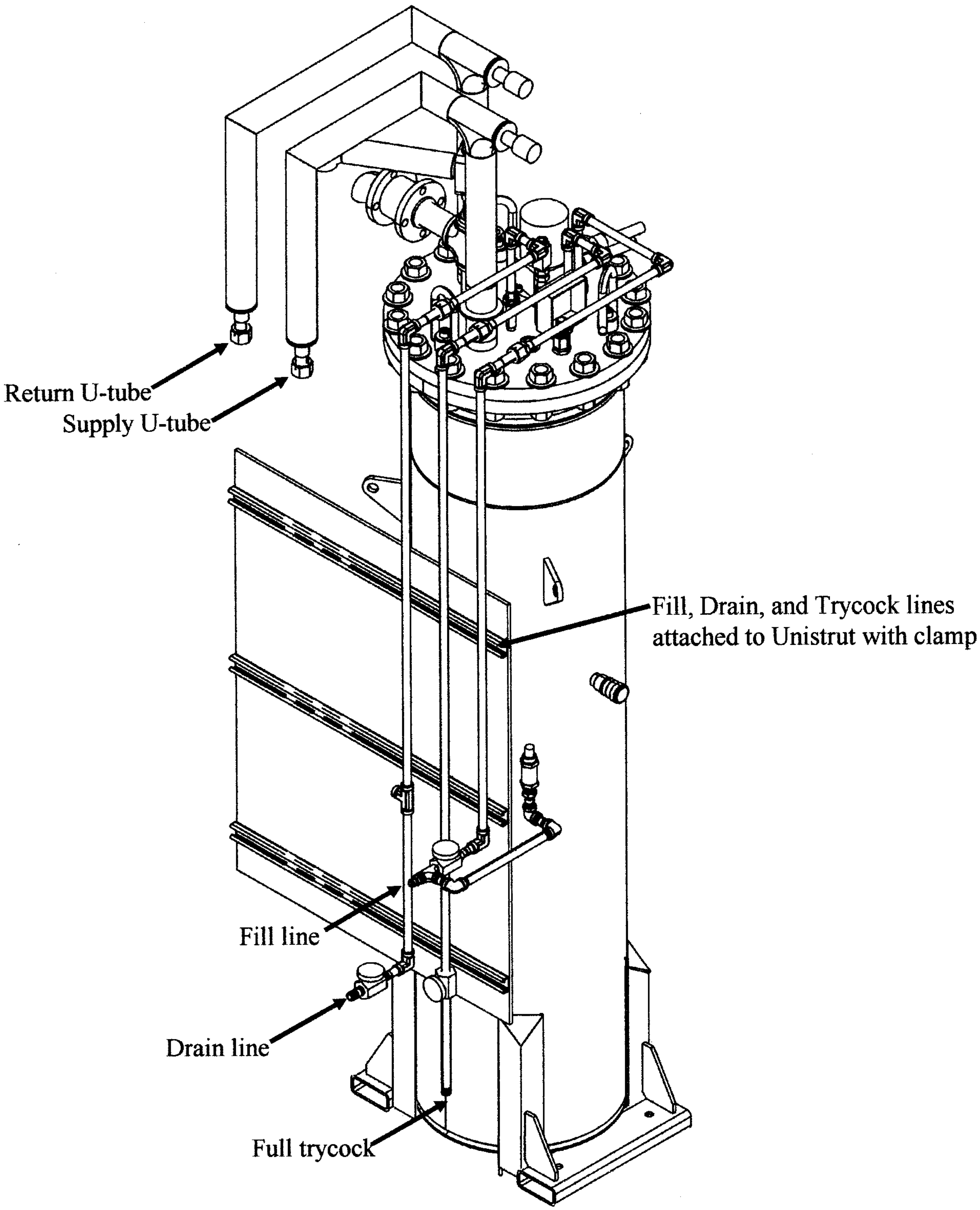


Figure 5.1: Piping attached to the vessel.

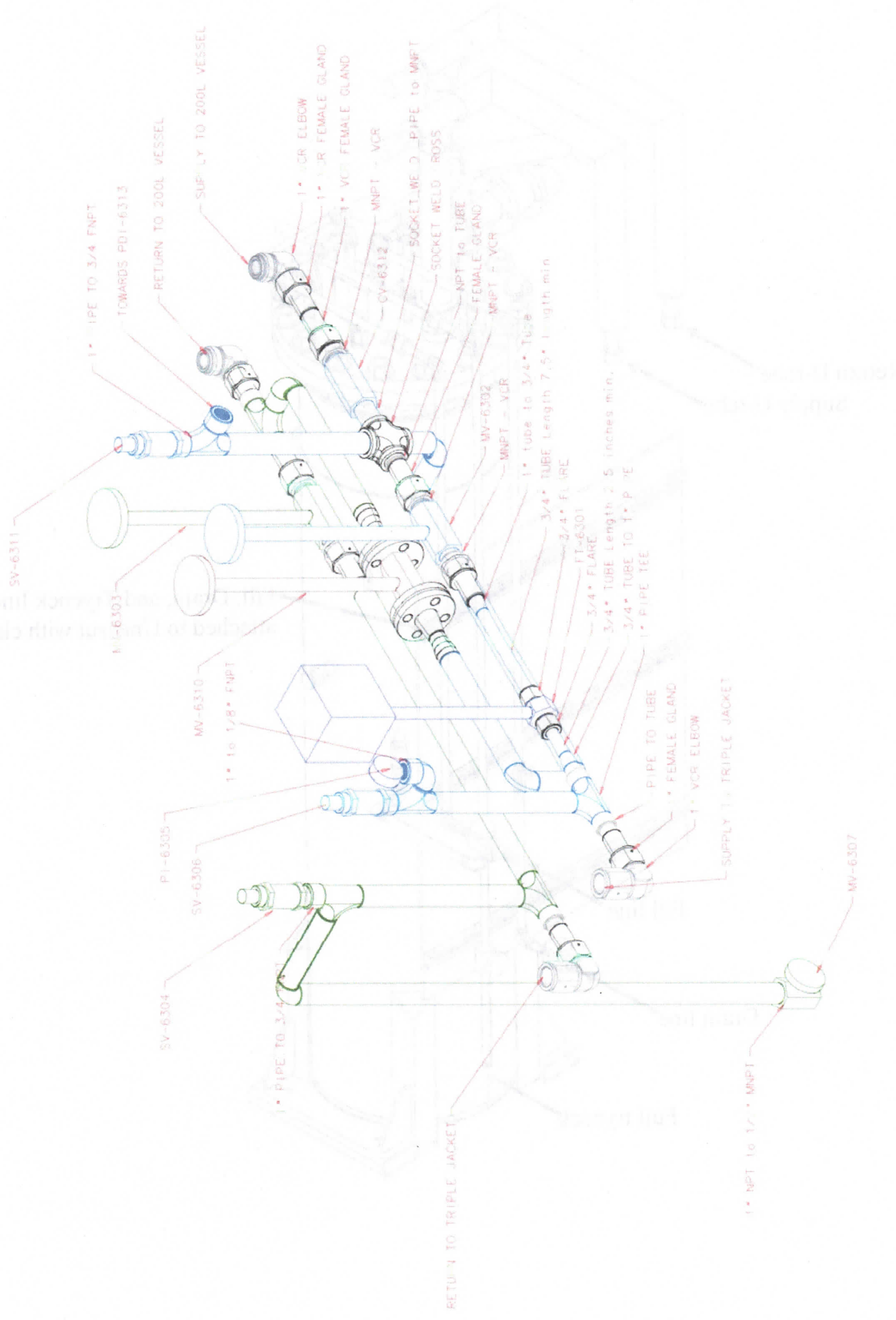


Figure 5.2: Valve box piping (contained in a foam box).

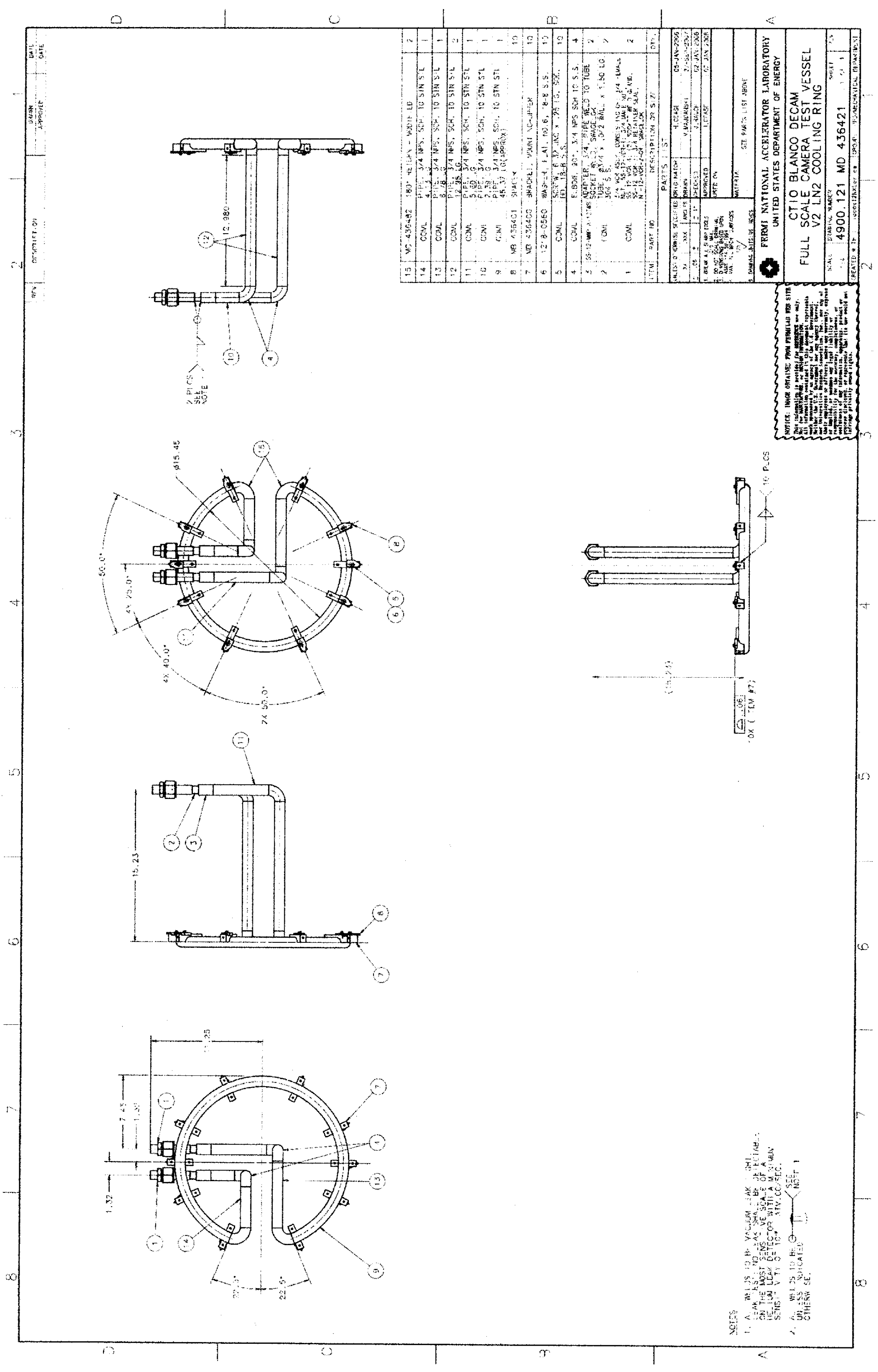


Figure 5.3: Cooling Ring piping.

The minimum thickness of the pipes is evaluated using the procedures in 304.1.2(a) of ASME B31.3. The minimum tube thickness for seamless or longitudinally welded piping for t<D/6 is given by:

$$t = \frac{PD}{2(SEW + PY)}$$

where: t = wall thickness, (t mfg is the manufacturers minimum wall thickness while t req'd is the thickness required by the above equation)

P = internal design pressure

D = outside diameter (manufacturers nominal value is used)

S = allowable stress from table A-1

E = quality factor from table A-1A or A-1B = 0.8 (worst case)

W = weld joint strength reduction factor = 1

Y = coefficient from Table 304.1.1 = 0.4

Table 5.1 summarizes the results of the wall thickness calculation.

Table 5.1. Cryogenic piping parameters

Pipe / Tube	*P* (psid)	*D* (in)	*S* (psi)	*E*	*t* req'd (in)	*t* mfg min (in)	MAWP (psid)
U-tube LN2 piping	165	1.315	16,700	0.8	0.007	0.116	3,037
Drain Line, Fill Trycock Line, and Fill Line for the DES pressure vessel	150	0.750	16,700	0.8	0.004	0.044	1,645
Vent Line	150	0.250	16,700	0.8	0.001	0.0315	3,744
Cooling Loop	150	1.050	16,700	0.8	0.006	0.0726	1,956
Cooling Loop	150	0.750	16,700	0.8	0.004	0.0378	1,403
Valve box (worst case OD and wall THK)	150	1.315	16,700	0.8	0.007	0.065	1,375

In the above six cases the manufacturer's minimum wall thickness of the piping is greater than the minimum thickness required by ASME B31.3.

The "unlisted components" installed in the piping system as defined in B31.3 Section 304.7.2 are shown in Table 5.2.

Table 5.2. Unlisted piping components.				
Component	*Source*	*Pressure rating [psig]*	*System Design Pressure (psig)*	*Comment*
Vacuum jacketed flex hose	Duraflex part # D010TVJAVCR-720	150[(a)]	150	----
Bayonet	PHPK, part # PBA-10	150[(b)]	150	----
See the valve and instrument list for other components.				

(a) http://dcs-docdb.fnal.gov:8080/cgi-bin/RetrieveFile?docid=1537&version=6&filename=Fermi_Triple_Jacketed_wgs.pdf

(b) PHPK literature states that "All bayonets have been computer analyzed to meet the ANSI/ASME B31.3 piping code requirements….".

The flexibility of the U-tube piping was analyzed using ANSYS. The model boundary conditions and results are summarized in Figures 5.2 and 5.3.

The thermal shrinkage was taken to be 321 x 10^{-5} $\Delta L/L$ for 304/316 Stainless (B31.3 Table C-1). The modulus of elasticity of 304 Stainless was input as 30.3 x 10^{6} psi (B31. Table C-6) along with a Poisson's Ratio of 0.30 (B31.3 para 319.3.3).

The model is comprised of ANSYS PIPE 16 (straight), and PIPE 18 (elbow) elements in which ANSYS calculates flexibility and stress intensification per B31.1. The stress intensification factors for B31.3 are the same as for B31.1.

As a check of the FEA model, a simple model consisting of a section of straight pipe was analyzed. The pipe was anchored at both ends and cooled from room temperature to liquid nitrogen temperature. The stress reported by the FEA model matched the result obtained by multiplying the unit thermal strain by the modulus of elasticity.

Per B31.3 Appendix P, the operating stress is computed using equation (P17a)

$$S_o = \sqrt{\left(|S_a| + S_b\right)^2 + 4S_t^2}$$

where the axial (S_a), bending (S_b), and torsional (S_t) stresses are combined and compared to the allowable stress S_{oA} in para. P302.3.5(d) where

$$S_{oA} = 1.25 f\left(S_c + S_h\right).$$

S_c is the basic allowable stress at the minimum metal temperature expected during the displacement cycle under analysis and S_h is the basic allowable stress at the maximum metal temperature expected during the displacement cycle under analysis. Both S_c and S_h were taken to be 16,700 psi. The stress reduction factor f was taken to be 1.0 because this system will see less than 1,000 cycles in its lifetime.

$$S_{oA} = 1.25 \times 1.0 \times \left(16,700 + 16,700\right) = 41,750 psi$$

A macro (available in the appendix) was used to retrieve S_a, S_b, and S_t from ANSYS and then compute the combined stress. The peak operating stress for the Supply U-tube was found to be 5,280 psi for the cold case (thermal shrinkage + 165 psid) and 295 psi for the warm case (165 psid loading only). The peak operating stress for the Return U-tube was found to be 6,826 psi for the cold case (thermal shrinkage + 165 psid) and 295 psi for the warm case (165 psid loading only).

Thus the operating stress range for both U-tubes is only a few thousand psi and does not exceed the allowable operating stress limit. These stresses are well below the 16,700 psi limit for the U-tube piping components.

The Fill, Drain, and Trycock lines were also analyzed using an FEA model to investigate the thermal stress. In the FEA model these lines were modeled as fixed to their respective VCR fittings on the top flange and to a clamp attached to the Unistrut frame (see Figure 5.1). Figures 5.4 thru 5.6 show the model results. Application of B31.3 equation P17a resulted in a peak stress of 6,254 psi for the Fill Line, 8,353 psi for the Drain Line, and 7,770 psi for the Fill Trycock line. Thus the stress in each line due to thermal shrinkage and internal pressure is less than the 16,700 psi allowable.

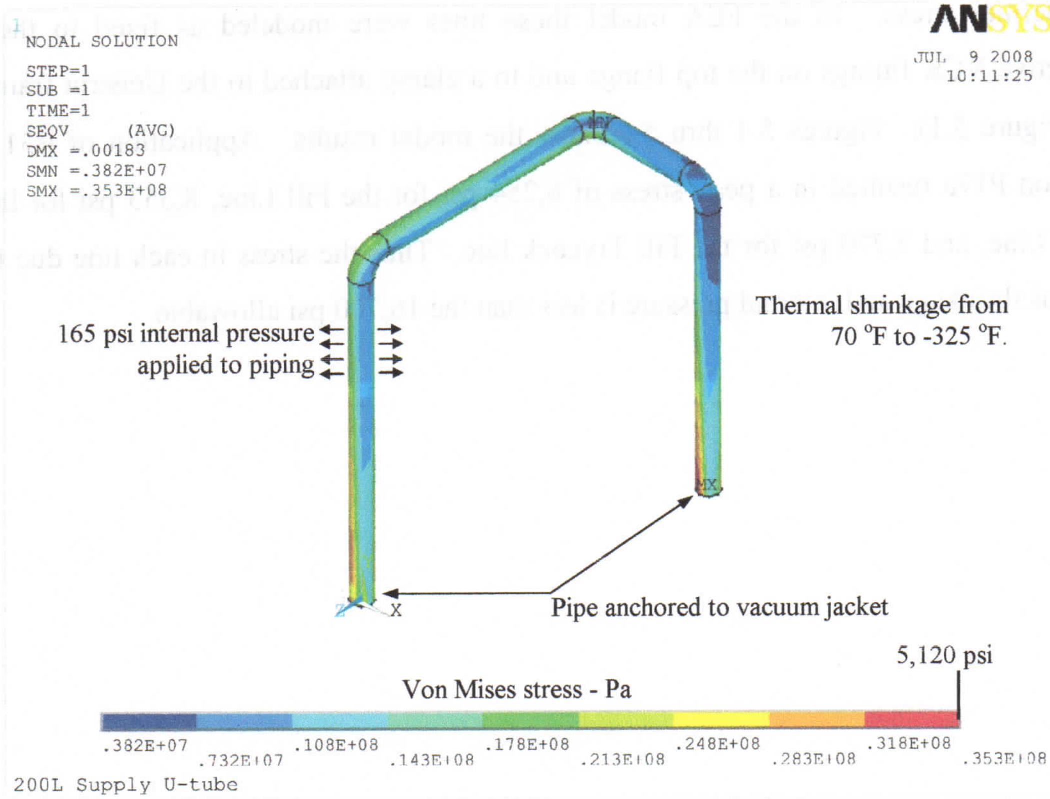


Figure 5.2: Supply U-tube FEA model boundary conditions and results.

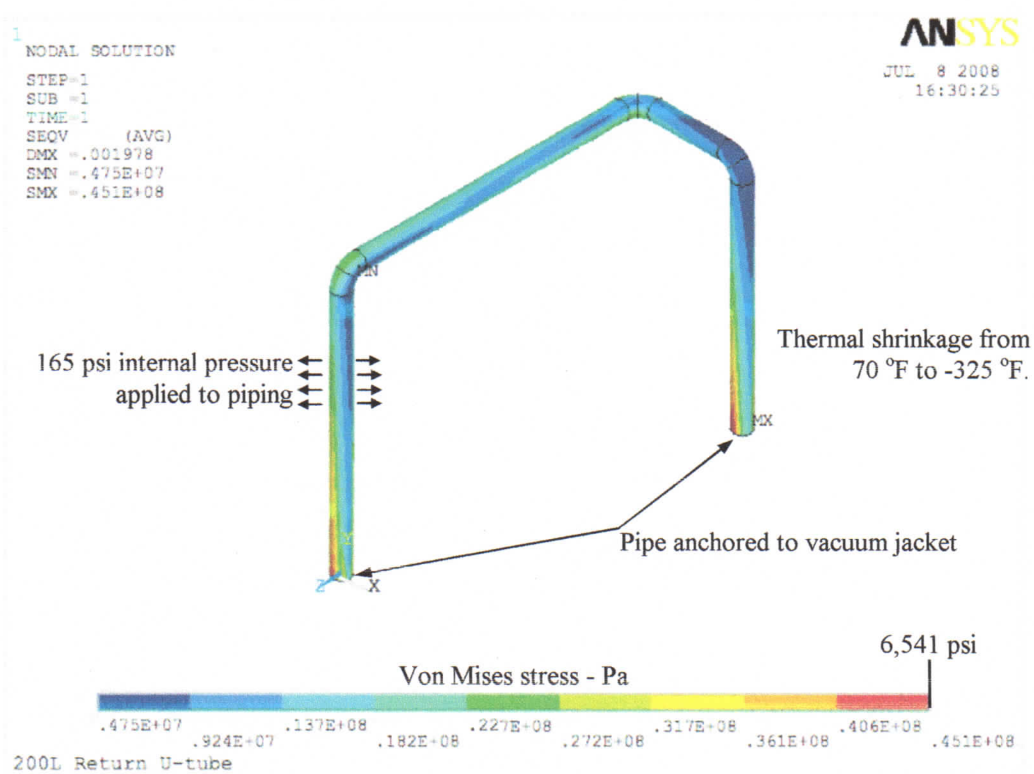


Figure 5.3: Return U-tube FEA model.

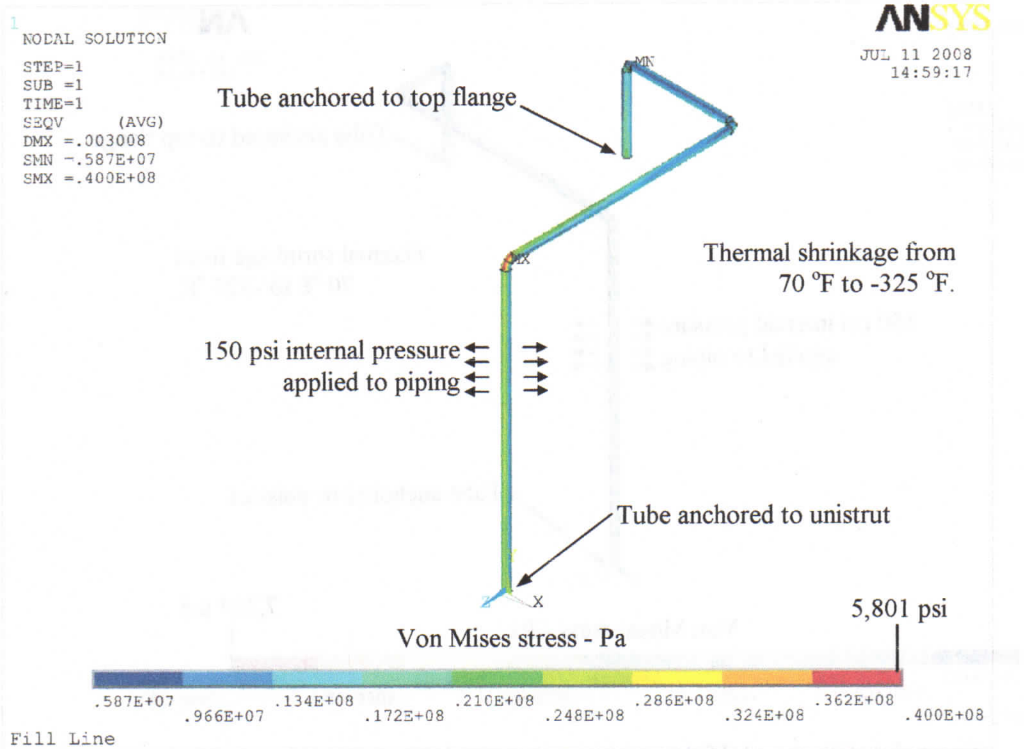


Figure 5.4: Fill line FEA model boundary conditions and results.

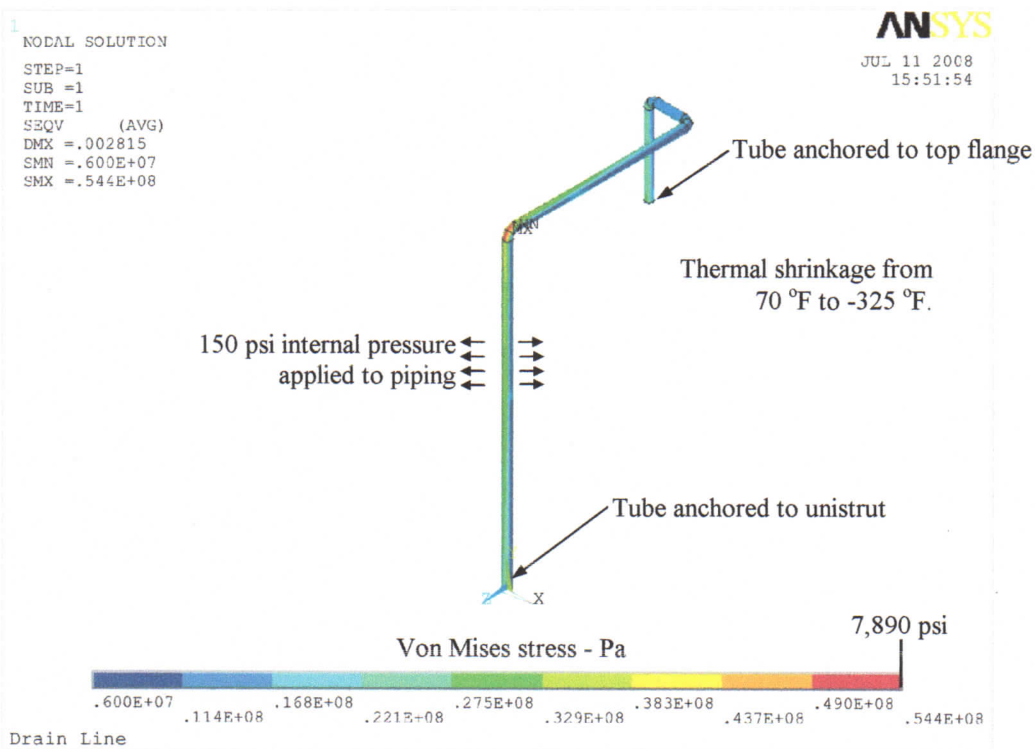


Figure 5.5: Drain line FEA model boundary conditions and results.

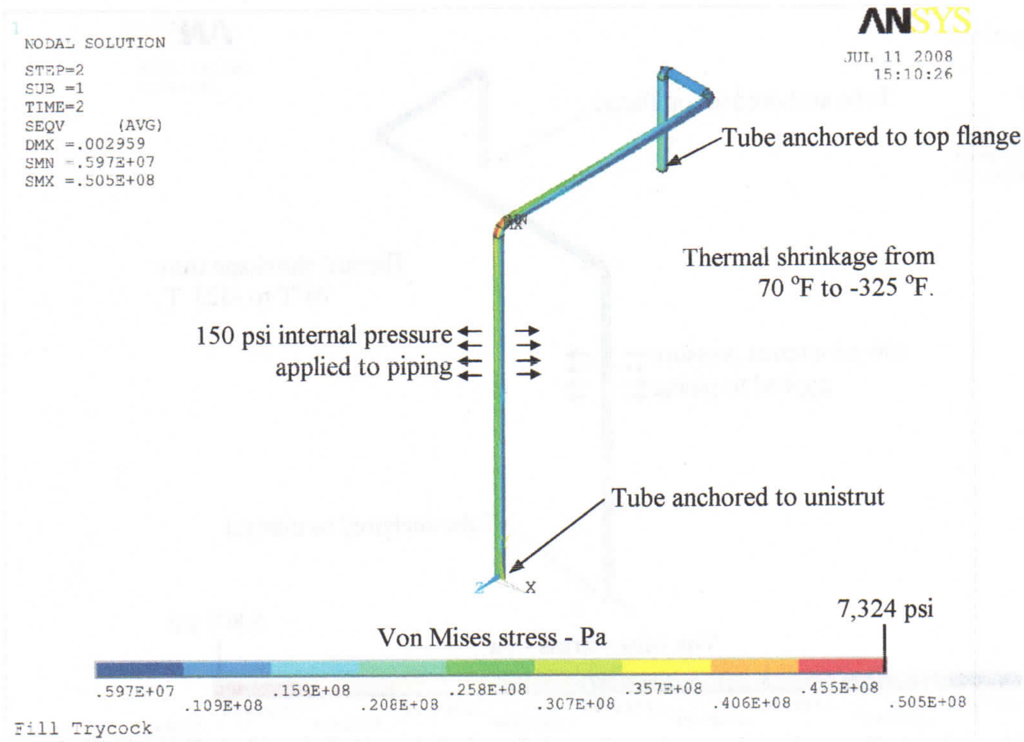


Figure 5.6: Fill trycock FEA model boundary conditions and results.

The Cooling Ring piping bends (Figure 5.3) are analyzed per para. 304.2.1 of the Code. The minimum required thickness is given by:

$$t = \frac{PD}{2((SEW/I)+PY)}$$

where: t = wall thickness

P = internal design pressure, 150 psid

D = outside diameter, 1.050 in.

S = allowable stress from table A-1, 16,700 psi for 304 S.S.

E = quality factor from table A-1A or A-1B = 0.8 (worst case)

W = weld joint strength reduction factor = 1

Y = coefficient from Table 304.1.1 = 0.4

I = factor for location in pipe bend: intrados, extrados and centerline

The following equations are used to determine I at the three locations:

at the intrados: $$I = \frac{4(R_1/D)-1}{4(R_1/D)-2}$$

at the extrados: $$I = \frac{4(R_1/D)+1}{4(R_1/D)+2}$$

at the centerline: $I = 1.0$

R_1 = bend radius of the tubing, 8.225 in.

The results are as follows:

t(in) for 8.225 in. radius: at intrados = 0.0061; extrados = 0.0057; centerline = 0.0059 (same as straight tube)

The bent pipe has a minimum wall thickness of 0.0726 inches so this requirement is satisfied.

6.0 Pressure relief system

Table 6.1: DES Lab A LN2 Test relief settings.			
Circuit	*Design pressure*	*Relief setting*	*Relief valve ID*
Drain line	150 psid	150 psig	SV-6213
Fill trycock line	150 psid	150 psig	SV-6213
Fill line	150 psid	150 psig	SV-6200-LN, SV-6213
Return U-tube	165 psid	150 psig	SV-6213
Supply U-tube	165 psid	150 psig	SV-6213

7.0 Welding and inspection

According to B31.3 Section 341, all piping in Normal Fluid Service shall be examined. All welding was performed by Lenny Harbacek whose stainless steel qualification is included in the Appendix. Eight butt welds were radiographed and the results are available as an attachement. The system contains 70 butt welds.

B31.3 requires the welding procedure for austenitic stainless steels to be qualified by impact tests of the weld metal and heat affected zone for wall thicknesses greater than 0.098 inch when used at liquid nitrogen temperatures. The 1" SCH 40 U-tube piping has a wall thickness of 0.133 inches. Fermilab does not have a qualified welding procedure for use of austenitic stainless steels at liquid nitrogen temperatures. However, the stress in this piping is far below the allowable stress. Low stress reduces the likelihood of brittle failure in the heat affected area. The ASME pressure vessel code recognizes the suitability of 304/304L & 316/316L for use at liquid nitrogen temperatures. In Section VIII Division 1, paragraph UHA-51(d)(1) exempts 304/304L and 316/316L from impact testing for both the base metals and the heat affected zones.

8.0 Pressure testing

The piping system will be pressure tested in accordance with Section 5034 of the Fermilab ES&H Manual and 345.5 of the Code. The test pressure is 110% of the design pressure which is 1.1 x 150 = 165 psig.

9.0 Appendix

post.dat

```
/post1

/sys, del results.res

esel,s,ename,,16

etab,sa,smisc,13
etab,sb,nmisc,90
etab,st,smisc,14

esel,s,ename,,17

etab,sa,smisc,37
etab,sb,nmisc,268
etab,st,smisc,38

esel,s,ename,,18

etab,sa,smisc,13
etab,sb,nmisc,91
etab,st,smisc,14

allsel

*get,ecnt,elem,,count  ! number of elements selected
*do,qq,1,ecnt          ! loop through the elements
/gopr
*get,el,elem,,num,min   ! get starting element, lowest number

*get,ssa,elem,el,etab,sa
*get,ssb,elem,el,etab,sb
*get,sst,elem,el,etab,st

/out,results,res,,append
res_%el%=sqrt((abs(ssa)+ssb)**2+4*sst**2)
/out

esel,u,elem,,el
*enddo
```

Page 1

Figure A-1: ANSYS macro used to compute operating stress.

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COPY

Welder Qualification Test Record

Welder's Name Leonard Harbacek Ident No. 122261 Date 03/19/99

Welding Process GTAW Type Manual

Test in Accordance With WPS # ES-155003 Root Open

Material Specification SA 53-B To Material Specification SA 53-B

P-No 1 To P-No 1 Thickness .280" Diam 6"

Filler Metal Specification SFA A5.18 Classification ER-70S-2 F-No 6

Thickness Deposited .280

Backing Argon Gas Shielding Argon

Position 6-G Progression Upward

Electrical Characteristics: Current DC Polarity Straight

Thickness Qualified .560" Max Diameter Qualified 2-7/8" O.D. and over

GUIDED BEND TEST RESULTS

Specimen No	Type	Figure	Results
1	Face	QW-462.3a	Acceptable
2	Face	QW-462.3a	Acceptable
3	Root	QW-462.3a	Acceptable
4	Root	QW-462.3a	Acceptable

Test Conducted By IFR Engineering Test No. 008-09-01 Date 3/19/99

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

By: [signature]

Date: 4/22/99

Figure A-2: Leonard Harbacek's welding qualification for stainless steel.

Fermilab August 14, 2008

To: Greg Bock
Particle Physics Division

From: Phil Pfund
Chair, Village & Misc. Cryogenic Safety Review Panel

Subject: DECam LN2 Closed Loop Safety Review

Dear Greg,

The Village & Misc. Cryogenic Safety Review Panel has completed its review of the DECam LN2 Closed Loop design and installation in Lab A.

Our review consisted of:

- Review of safety related documentation for the LN2 loop. All of the DECam LN2 documentation and updates are maintained by Herman Cease at: http://des-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=1537 login: desreviews , password: DESrev The documentation related to the closed loop is collected by subject area and consists of:
  - Document List
  - (1a) 200L vessel engineering note and supporting documents
  - (1b) 200L 18 inch flange engineering note and supporting documents
  - (1c) 200L 18 inch flange pressure test and supporting documents
  - (2) Process and instrumentation diagram, 7/31/08
  - (3) Instrumentation and valve list, 8/11/08
  - (4) Failure Mode and Effect analysis, 8/11/08
  - (5) What-if analysis
  - (6) Operating procedures
  - (7) SiDet ODH analysis and supporting documents
  - (8) Piping system engineering note and supporting documents
- Individual panel member telephone and e-mail exchanges with Herman Cease from initiation of the review on 1/25/08 through 8/14/08 resulting in revisions to the documentation listed above.
- 2/1/08 visit to Lab A by panel members to view the planned installation location and to discuss design and pending documentation with Herman Cease.
- 5/5/08 meeting with Herman Cease to discuss status of the design and documentation.
- 8/6/08 visit to Lab A by panel members to view status of the installation and to discuss comments to documentation with Herman Cease.
- 8/14/08 visit to Lab A by panel members to view the final installation.

Based on the above listed review activities, we are satisfied that the DECam LN2 closed loop in Lab A as designed and installed can be operated safely. We recommend that you authorize the operation.

Regards,

Phil Pfund
On behalf of the Village & Misc. Cryogenic Safety Review Panel

Copy: Wayne Schmitt
Herman Cease
Panel Members (Brian DeGraff, Tom Page, Dave Pushka)
Arkadiy Klebaner

FMEA

T. Tope 8-11-08

Check valves

Type	Tag	Tag	Service	Failure or Error Mode	Hazard or Effect	Hazard Class	Remarks
CV	6312	LN2	Check valve supply line	Fails open	Pump damage	Safe	Operational problem - Liquid draining back while pump is off could over-speed the impeller. Thermal tests cannot be conducted if the pump is damaged.
CV	6312	LN2	Check valve supply line	Fails closed	Pump dead heads	Safe	Operational problem - Lack of flow would be indicated by FT-6301, pump could eventually cavitate due to heat input into static liquid. There is a very low probability that the "swing" style check valve could be completely blocked.

Filter

Type	Tag	Tag	Service	Failure or Error Mode	Hazard or Effect	Hazard Class	Remarks
F	6217	LN2	Instrument line filter	Fails open	Normal	Safe	OK - Small possibility particulate matter could stop PRV-6202 from sealing leading to excessive GN2 venting.
F	6217	LN2	Instrument line filter	Fails closed (plugged)	instrument line vent is closed	Safe	Operational problem - can't measure vent rate which helps understand the thermal tests.

Flow instruments

Type	Tag	Tag	Service	Failure or Error Mode	Hazard or Effect	Hazard Class	Remarks
FI	6201	LN2	Instrument line flow indicator	Incorrect reading high	incorrect flow	Safe	Operational problem -Heat leak calculations may be inaccurate.
FI	6201	LN2	Instrument line flow indicator	Incorrect reading low	incorrect flow	Safe	Operational problem -Heat leak calculations may be inaccurate.
FT	6301	LN2	Supply line flow transmitter	Incorrect reading high	incorrect flow	Safe	Operational problem -Heat leak calculations may be inaccurate.
FT	6301	LN2	Supply line flow transmitter	Incorrect reading low	incorrect flow	Safe	Operational problem -Heat leak calculations may be inaccurate.

Heating elements

Type	Tag	Tag	Service	Failure or Error Mode	Hazard or Effect	Hazard Class	Remarks
HTR	6102	LN2	Heater inside reservoir	OFF	Loss of vapor pressure	Safe	Operational problem - Without the heater to balance the cryocooler, the system will depressurize and the cooling loop performance degrades due to increased bubble size in the pumped loop. Thermal tests cannot be conducted without the heater.
				ON	Heater assembly overheats	Safe	Operational problem - PLC will shut off heater based on TE-6211. If PLC fails, hardware thermal switch set at 55 C will cut AC power to heater. Thermal tests cannot be conducted with a run away heater.
				ON	LN2 vaporized	Safe	Operational problem - SV-6213 has enough capacity for LN2 vaporized by the heater. Thermal tests cannot be conducted with a runaway heater.
HTR	6405	LN2	Trim heater on Heat exchanger	OFF	Can't test system performance	Safe	Operational problem - Can't perform thermal tests without HTR-6405 which simulates experimenter hardware heat dissipation.
				ON	Heater assembly overheats	Safe	Operational problem - PLC will shut off heater based on TE-6404. If PLC fails, hardware thermal switch set at 55 C will cut AC power. Can't conduct thermal tests with a runaway heater.
				ON	LN2 vaporized	Safe	Operational problem - SV-6213 has enough capacity for LN2 vaporized by the heater. Thermal tests cannot be conducted with a runaway heater.

Liquid level transmitters

Type	Tag	Tag	Service	Failure or Error Mode	Hazard or Effect	Hazard Class	Remarks
LT	6207	LN2	Level Transmitter	Incorrect reading high	Pump could cavitate	Safe	Operational problem - PDI-6313 also provides level information. If the pump is run without enough NPSH, it may be damaged.
LT	6207	LN2	Level Transmitter	Incorrect reading low	No Hazard	Safe	Operational problem - Indication of low liquid level is redundant with PDI-6313

Manual valves

Type	Tag	Tag	Service	Failure or Error Mode	Hazard or Effect	Hazard Class	Remarks
MV	6201	LN2	Instrument Line Isolation valve on flow meter 6201	Fails open	No Hazard	Safe	OK - normal position
MV	6201	LN2	Instrument Line Isolation valve on flow meter 6201	Fails closed	Instrument line vent is closed	Safe	Operational problem - SV-6218 can vent flow from supply dewar. FI-6201 will not be available to aid in heat leak calculations.
MV	6204	LN2	Fill Port,	Fails open	Vessel empties	Safe	Operational problem - Vapor pressure pushes LN2 out of vessel and onto ground outside of Lab A if supply dewar is not attached. Thermal tests cannot be conducted.
MV	6204	LN2	Fill Port,	Fails closed	Can't fill vessel	Safe	Operational problem - If a dewar is attached, SV-6200 provides a trapped volume relief. Can't fill system and conduct thermal tests if MV-6204 is closed.
MV	6205	LN2	Drain Port, Manual Shutoff Valve	Fails open	Vessel empties	Safe	Operational problem - Vapor pressure pushes LN2 out of vessel and onto ground outside of Lab A. Can't conduct thermal tests without LN2.
MV	6205	LN2	Drain Port, Manual Shutoff Valve	Fails closed	Can't empty vessel	Safe	OK - Dewar could be emptied thru MV-6204 if MV-6205 is closed.
MV	6208	LN2	Full Try Cock, Manual valve	Fails open	Dewar blows down	Safe	Operational problem - Need ~ 100 psig of pressure for pressure drop to be tolerable in pumped lines. < 100 psig may lead to inadequate cooling and the thermal tests will fail.
MV	6208	LN2	Full Try Cock, Manual valve	Fails closed	Over fill vessel	Safe	Operational problem - PDI-6313 and LT-6207 also provide level indication. If vessel is overfilled SV-6231 can handle the excess liquid. Pressure control will be difficult if vessel is too full due to small vapor volume and high heat leak.
MV	6216	LN2	Instrument Line Isolation valve	Fails open	Cannot isolate instrument line	Safe	Maintenance problem - If pressure gauge, pressure transmitter, or back pressure regulator fail, system will have to be blown down for repair. Thermal tests will have to stop.
MV	6216	LN2	Instrument Line Isolation valve	Fails closed	isolates pressure gages and regulator valve	Safe	Operational problem - no pressure indication. PI-6206 could be used to measure the vapor pressure + liquid head.
MV	6302	LN2	LN2 dewar pump outlet isolation	Fails open	Can't isolate pump discharge	Safe	Operational problem - Can't isolate pump from flexible hose and cooling ring to examine cryostat only heat leak or perform maintenance on these parts.
MV	6302	LN2	LN2 dewar pump outlet isolation	Fails closed	Can't pump liquid to cooling ring	Safe	Operational problem - Can't perform thermal tests. Potential trapped volume or pump dead head relieved by SV-6311.
MV	6303	LN2	Return Line, Manual valve near reservoir	Fails open	Can't isolate pump supply	Safe	Operational problem - Can't isolate pump from flexible hose and cooling ring to examine cryostat only heat leak or perform maintenance on these parts.
MV	6303	LN2	Return Line, Manual valve near reservoir	Fails closed	Can't pump liquid to cooling ring	Safe	Operational problem - Can't perform thermal tests. Potential trapped volume or pump dead head relieved by SV-6304.
MV	6307	LN2	Return Line port	Fails open	Liquid is pumped out of system	Safe	Operational problem - liquid will be pumped out of MV-6307 and onto the ground outside of Lab A. Thermal tests will be disrupted.
MV	6307	LN2	Return Line port	Fails closed	Can't cool down piping according to procedure	Safe	Operational problem - can't cool down piping according to procedures. Thermal tests will not be started until valve is fixed.
MV	6310	LN2	Manual Control Valve, bypass near reservoir	Fails open	Very little flow to cooling ring	Safe	Operational problem - flow to cooling ring will be inadequate and cooling tests can't be conducted.
MV	6310	LN2	Manual Control Valve, bypass near reservoir	Fails closed	All pump flow goes thru cooling ring	Safe	Operational problem - pump may operate at an undesirable point on the pump curve and provide poor cooling to the cooling ring. System and thermal tests can't be performed.

Pressure indicating gauges

Type	Tag	Tag	Service	Failure or Error Mode	Hazard or Effect	Hazard Class	Remarks
PDI	6313	LN2	Differential pressure indicator, supply return	Incorrect reading high	Pump could cavitate	Safe	Operational problem - LT-6207 also provides level information. Indication of high liquid level must be investigated.
PDI	6313	LN2	Differential pressure indicator, supply return	Incorrect reading low	No Hazard	Safe	Operational problem - Indication of low liquid level must be investigated.
PE	6101	V	Pressure element for reading the vacuum pressure	Incorrect reading - low	Insulating vacuum worse than indicated	Safe	Operational problem - heat input could exceed cryocooler capacity and system would start venting which could disrupt the thermal tests.
PE	6101	V	Pressure element for reading the vacuum pressure	Incorrect reading - high	Insulating vacuum better than indicated	Safe	Operational problem - time could be spent investigating a non-existent problem.
PI	6206	LN2	Drain Port, Pressure Indicator	Incorrect reading - low	No Hazard	Safe	OK - Under most circumstances PI-6209 provides a redundant reading
PI	6206	LN2	Drain Port, Pressure Indicator	Incorrect reading - high	No Hazard	Safe	OK - Under most circumstances PI-6209 provides a redundant reading
PI	6209	N2	Vessel Pressure Indicator	Incorrect reading - low	No Hazard	Safe	OK - PT-6215 provides a redundant reading

PI	6209	N2	Vessel Pressure Indicator	Incorrect reading - high	No Hazard	Safe	OK - PT-6215 provides a redundant reading
PI	6305	LN2	Supply line pressure indicator near reservoir	Incorrect reading - low	No Hazard	Safe	OK- Reduntant with PI-6209
PI	6305	LN2	Supply line pressure indicator near reservoir	Incorrect reading - high	No Hazard	Safe	OK- Redundant with PI-6209
PI	6401	LN2	Supply line, Pressure indicator near heat exchanger	Incorrect reading - low	No Hazard	Safe	OK- Reduntant with PI-6202
PI	6401	LN2	Supply line, Pressure indicator near heat exchanger	Incorrect reading - high	No Hazard	Safe	OK - Reduntant with PI- 6202
PI	6402	LN2	Return line, Pressure indicator near heat exchanger	Incorrect reading - low	No Hazard	Safe	OK -Reduntant with PI-6201
PI	6402	LN2	Return line, Pressure indicator near heat exchanger	Incorrect reading - high	No Hazard	Safe	OK - Reduntant with PI-6201

Pressure regulators

PRV	6202	N2	Instrument Line, Boil-Off Regulator	Fails open	Dewar blows down	Safe	Operational problem - Can't perform cooling tests if system loses pressure.
PRV	6202	N2	Instrument Line, Boil-Off Regulator	Fails closed	Dewar pressure builds	Safe	Operational problem - SV-6213 will vent excess pressure if cryocooler cannot keep up with heat leak. Heat leak cannot be measured thru FI-6201.

Pressure transmitters

PT	6215	N2	Pressure Transmitter, Vessel pressure	Incorrect reading -low	No Hazard	Safe	OK - PI-6209 provides a redundant reading
PT	6215	N2	Pressure Transmitter, Vessel pressure	Incorrect reading - high	No Hazard	Safe	OK - PI-6209 provides a redundant reading

Pumps

Pump	6103	N2	Submersible LN2 pump	Cavitates	Damage to pump	Safe	Operational problem - Can't provide LN2 to cooling ring. Cooling tests cannot be performed.
Pump	6103	N2	Submersible LN2 pump	Fails off	No Hazard	Safe	Operational problem - Can't provide LN2 to cooling ring. Cooling tests cannot be performed.
Pump	6103	N2	Submersible LN2 pump	Fails On	No Hazard	Safe	OK - power can be removed at local fuse panel if required. Overpressurization from a runaway pump speed is releived through SV-6213

Rupture disks

RD	6214	LN2	Reservoir Positive pressure 2nd main relief	Fails closed	No Hazard	Safe	OK - Dewar will vent thru SV-6213 if necessary
RD	6214	LN2	Reservoir Positive pressure 2nd main relief	Fails open	No Hazard	Safe	Operational problem - System will depressurize and cooling tests cannot be performed.

Variable speed drive

SC	6104		Speed Control for LN pump	Fails off or too slow	No Hazard	Safe	Operational problem - Can't provide LN2 to cooling ring. Cooling tests cannot be performed.
SC	6104		Speed Control for LN pump	Fails On or too fast	No Hazard	Safe	OK - power can be removed at local fuse panel if required. Cooling tests cannot be performed.

Pressure relief valves

SV	6100	V	Vacuum positive pressure relief on reservoir vacuum jacket	Fails open	High boil off rate	Safe	Operational problem - boiloff vents thru SV-6213. Liquid loss will be high and cooling tests will not be possible to perform.
SV	6100	V	Vacuum positive pressure relief on reservoir vacuum jacket	Fails closed	Vacuum space not adequately relieved.	Safe	OK - Requires double failure, vacuum pumpout port associated with VV-6105 will provide some relief capacity.
SV	6200	LN2	Fill port, trapped volume relief	Fails open	Dewar blows down	Safe	Operational problem - If MV-6204 is open or the filling process is underway LN2 will spill onto the ground outside Lab A.
SV	6200	LN2	Fill port, trapped volume relief	Fails closed	Trapped volume not relieved	Safe	OK - Low probability of a quality Circle-Seal relief valve failing completely shut. As pressure in the trapped volume exceeded the relief valve set point, the probability of a stuck relief valve opening would increase. All trapped volume reliefs were tested by Fermilab prior to installation.
SV	6213	LN2	Reservoir Positive pressure main relief	Fails open	Dewar blows down	Safe	Operational problem - can't perform cooling tests.
SV	6213	LN2	Reservoir Positive pressure main relief	Fails closed	No Hazard	Safe	OK - Dewar will vent thru RD-6214 if necessary.
SV	6218	LN2	Trapped volume relief for FI 6201	Fails open	No Hazard	Safe	Operational problem - Can't measure heat leak thru FI-6201.
SV	6218	LN2	Trapped volume relief for FI 6201	Fails closed	FI-6201 is over pressurized	Safe	OK - Low probability of a quality Circle-Seal relief valve failing completely shut. As pressure in the trapped volume exceeded the relief valve set point, the probability of a stuck relief valve opening would increase. All trapped volume reliefs were tested by Fermilab prior to installation.
SV	6304	LN2	Return line, trapped volume relief near reservoir	Fails open	Dewar blows down, pumped liquid lost	Safe	Operational problem - Liquid would be pumped out the relief and the system would depressurize. Cooling tests could not be performed.
SV	6304	LN2	Return line, trapped volume relief near reservoir	Fails closed	Trapped volume not relieved	Safe	OK - Low probability of a quality Circle-Seal relief valve failing completely shut. As pressure in the trapped volume exceeded the relief valve set point, the probability of a stuck relief valve opening would increase. All trapped volume reliefs were tested by Fermilab prior to installation.
SV	6306	LN2	Supply line trapped volume relief near reservoir	Fails open	Dewar blows down, pumped liquid lost	Safe	Operational problem - Liquid would be pumped out the relief and the system would depressurize. Cooling tests could not be performed.
SV	6306	LN2	Supply line trapped volume relief near reservoir	Fails closed	Trapped volume not relieved	Safe	OK - Low probability of a quality Circle-Seal relief valve failing completely shut. As pressure in the trapped volume exceeded the relief valve set point, the probability of a stuck relief valve opening would increase. All trapped volume reliefs were tested by Fermilab prior to installation.
SV	6311	LN2	Supply line trapped volume relief reservoir check valve	Fails open	Dewar blows down, pumped liquid lost	Safe	Operational problem - Liquid would be pumped out the relief and the system would depressurize. Cooling tests could not be performed.
SV	6311	LN2	Supply line trapped volume relief reservoir check valve	Fails closed	Trapped volume not relieved	Safe	OK -Low probability of a quality Circle-Seal relief valve failing completely shut. As pressure in the trapped volume exceeded the relief valve set point, the probability of a stuck relief valve opening would increase. All trapped volume reliefs were tested by Fermilab prior to installation.

Temperature elements

TE	6210	N2	Temperature Element, Condenser Temperature	Incorrect reading - low	Cryocooler performance misrepresented	Safe	Operational problem - Heat leak calculations will be inaccurate
TE	6210	N2	Temperature Element, Condenser Temperature	Incorrect reading - high	Cryocooler performance misrepresented	Safe	Operational problem - Heat leak calculations will be inaccurate
TE	6211	N2	Temperature element, Top Reservoir Gas Temperature	Incorrect reading - low	Cooling performance misrepresented	Safe	Operational problem - Heat leak calculations will be inaccurate. Heater 6102 protected with thermal switch set at 55C.
TE	6211	N2	Temperature element, Top Reservoir Gas Temperature	Incorrect reading - high	Cooling performance misrepresented	Safe	Operational problem - Heat leak calculations will be inaccurate. Heater 6102 protected with thermal switch set at 55 C.
TE	6403	N2	Return line, Temperature indicator near heat exchanger	Incorrect reading - low	Cooling performance misrepresented	Safe	Operational problem - Heat leak calculations will be inaccurate
TE	6403	N2	Return line, Temperature indicator near heat exchanger	Incorrect reading - high	Cooling performance misrepresented	Safe	Operational problem - Heat leak calculations will be inaccurate
TE	6404	N2	Supply line, Temperature indicator near heat exchanger	Incorrect reading - low	Cooling performance misrepresented	Safe	Operational problem - Heat leak calculations will be inaccurate. Heater 6102 protected with thermal switch set at 55C.
TE	6404	N2	Supply line, Temperature indicator near heat exchanger	Incorrect reading - high	Cooling performance misrepresented	Safe	Operational problem - Heat leak calculations will be inaccurate. Heater 6102 protected with thermal switch set at 55C.

Vacuum pumpouts

VV	6105	V	Vacuum pump out port	Fails open	High boil off rate	Safe	Operational problem - boiloff vents thru SV-6213. Liquid loss will be high and cooling tests will not be possible to perform.
VV	6105	V	Vacuum pump out port	Fails closed	Vacuum space pressure can't be lowered	Safe	Operational problem - Poor vacuum could lead to a high boiloff rate and venting thru SV-6213. Cool tests could not be performed.

Accelerometer

ZT	6406	LN2	Accelerometer attached to Heat Exchanger	Incorrect reading - low	Vibration magnitude misrepresented	Safe	Operational problem - System vibration will be misunderstood
ZT	6406	LN2	Accelerometer attached to Heat Exchanger	Incorrect reading - high	Vibration magnitude misrepresented	Safe	Operational problem - System vibration will be misunderstood